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A DYNAMIC STUDY OF FACTORS IMPACTING ON THE TANK COMMANDER'S TARGET SELECTION PROCESS

Glenn Joseph Broussard

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THESIS

A DYNAMIC STUDY OF FACTORS
IMPACTING ON THE TANK COMMANDER'S
TARGET SELECTION PROCESS

by

Glenn Joseph Broussard

March 1979

Thesis Advisors: S. H. Parry
H. J. Larson

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(20. ABSTRACT Continued)

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A Dynamic Study of Factors Impacting on the Tank Commander's Target Selection Process

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis presents a dynamic study of the target selection process of the current generation of U. S. Army tank commanders. Eleven relevant factors were investigated utilizing a 1/16 Replication of the 2^{11} factorial experimental design. The development and basic characteristics of this experimental design are discussed as an introduction to the actual experiment conducted. The methodology used in conducting the experiment as well as the major effort devoted to establishing the data base are presented prior to the discussion of the analysis. Factors and interactions impacting significantly on the target selection process were identified using analysis of variance techniques and an interpretation of these is given. A target selection model based on a best fit regression on the data is proposed as a viable alternative to those target selection models presently used in existing high resolution combined arms simulation models.

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I. INTRODUCTION

Much emphasis has been placed in recent years on the use of the combined arms simulation model in making decisions regarding alternative weapon systems. This emphasis, particularly in light of the vastly changing modern battlefield, makes it imperative that every possible consideration be given to the verification, modification, and continued improvement of every facet of these important decision-making tools. Verification of these models is at best extremely difficult and in many aspects practically impossible short of actual combat. Nevertheless, an intelligent study based on sound statistical theory can provide invaluable insight into the verification of numerous specific sub-models inherent in these models.

The modeling of the target selection process of the individual tank commander in combat is an inherent sub-model of every existing high resolution combined arms simulation model. This specific sub-model unquestionably impacts greatly on the overall realism achieved in any combat simulation involving an appreciable armor force. Simply stated these models attempt to answer the following two basic questions:

> Given a situation in time where an individual tank commander is faced with an array of possible targets:
>
> 1. What is the scheme used by the tank commander in assigning engagement priorities to the individual targets presented in the array?

2. What decision is made by the tank commander with respect to engaging or not engaging the targets in his prioritized target list?

In all presently existing simulation models, the range between target and observer is considered the paramount factor used by a tank commander in assigning his engagement priorities. The target selection model presently used in the Dynamic Tactical Simulation Model (DYNTACS) for example calculates an adjusted range (ADJR) for each target in the array of possible targets, and then assigns engagement priorities based on the minimum value of this adjusted range. This adjusted target range is computed using the following equation:

$$\text{ADJR} = \frac{\text{RR}}{1 - \text{C}} + \sum_{i=1}^{6} \text{RAF}_i$$

where,

RR = target to observer range

C = cover fraction presently available to the target

RAF_i = range adjustment factor for factor i, where i refers to the following:

1. target weapon type
2. whether the target is presently the observer's target
3. whether another friendly element is firing at the target
4. whether the target fired in the observer's previous event
5. whether the target fired at the observer in his previous event
6. whether the target is in the observer's sector of responsibility

It is important to note that the values of RAF_i, $i = 1,2,\ldots,6$ are specified as input data and are thus assigned arbitrary values based on the judgement of the military analysts conducting the simulation study. Research indicates that no prominent attempt has been made to verify this model nor to ascertain those values of the range adjustment factors that best relate to actual battlefield conditions. Furthermore, the full impact of adjusting range with regard to cover fraction of the enemy target, specifically $\frac{RR}{1 - C}$ in the model, although basically not counter intuitive, is nonetheless not substantiated either.

Range is also the paramount factor incorporated in the target selection model presently used in the Simulation of Tactical Alternative Responses (STAR) model. In STAR priorities of targets are assigned solely on the basis of danger state arrays specified as input data. These arrays define a unique priority scheme for all possible target types within each of the three distinct rangebands defined as follows: less than 1000 meters, between 1000 and 2000 meters, and greater than 2000 meters. Thus in STAR a target within a lesser rangeband will always receive higher priority than a target within a greater rangeband. Additionally, if two or more targets receive the same priority, which will occur whenever two targets of the same type are encountered within the same rangeband, priority is always given to the target nearest the observer. It should be evident that in the present version of STAR range is essentially the only

factor considered in target selection and that quite possibly a very small range differential often becomes the sole basis for selecting one target over another. Again as in DYNTACS the priority schemes established in the danger state arrays reflect the judgement of the military analysts conducting the simulation study.

Obvious shortcomings exist in either of the target selection models discussed above. Additionally, another major shortcoming which is perhaps not so obvious yet considered very relevant characterizes both models. As stated previously both models allow the military analyst wide discretion in his selection of input values relative to the target selection process. The lack of empirical data forces the analyst to select these values based on his own perception of current doctrine relating to the target selection phenomenon. Thus the models at best tend to predict 'what should be done in the simulated situation' rather than 'what would be done in the actual situation'. This subtle difference directly impacts on the overall realism achieved by the model.

The general shortcomings discussed above, and in particular the acknowledged inadequacy of the target selection model presently used in STAR, directly influenced the initiation of the study incorporated in this thesis. The immediate goal of this study was to investigate and to identify the relative importance of the many factors considered by a tank commander in his assignment of

engagement priorities and in his decision to engage or not to engage a specific target. The ultimate goal of the study was to enhance the realism achieved in STAR by developing a realistic target selection model based on and substantiated by current and well-founded empirical data.

This thesis discusses in detail the general methodology used in conducting this study. Chapter II discusses the general characteristics and development of the $2^{(n-p)}$ Fractional Factorial experiment and relates directly to the actual experimental plan used and discussed at length in Chapter III. Chapter III also defines the specific dependent and independent variables investigated in the study and presents an in-depth discussion of the considerations and efforts allocated to the establishment of the data base used in the analysis. Chapter IV discusses the general methodology used in the actual analysis and presents a basic theory of the nature of the various statistical tools used in the analysis. Chapters V and VI summarize the actual analyses that were conducted for each of the dependent variables investigated and identifies those factors and interactions which were found to significantly impact on the target selection process. An explanation of the nature and impact of the factors and interactions thus identified is also presented. A discussion of a proposed target selection model as a possible enhancement to the STAR model is presented in Chapter VII. Appendices include a sample of

the actual questionnaire used in the collection of data and a summary of statistics characterizing the individuals who participated in the study. The listings of two computer programs that were used extensively in the analysis are also provided.

II. THE $2^{(n-p)}$ FRACTIONAL FACTORIAL

A. THE 2^n FACTORIAL

A factorial experiment is one in which all levels of a given factor are combined with all levels of every other factor in the experiment. This experimental design has become widely accepted as an efficient way of carrying out experiments involving many different factors. In general if $\underline{n}$ factors are considered each at $\underline{k}_i$ levels, then the total number of treatment combinations required to conduct a factorial experiment, henceforth referred to as the size of the experiment, is calculated as follows:

$$\text{Size} = k_1 \cdot k_2 \cdot k_3 \cdots k_n = \prod_{i=1}^{n} k_i \, .$$

The 2^n Factorial is a special case where $\underline{n}$ factors are considered each at two levels. It can easily be seen that a 2^n Factorial requires 2^n measurements for one complete replication and that this size quickly becomes uneconomical for most practical applications involving a large number of factors. In a 2^{11} Factorial for example, where 11 factors are to be investigated each at two levels, a total of 2048 observations will be required for a single replication of the experiment. Additionally, if the experiment is to yield an estimate of random error, a primary consideration in

most practical problems, at least one additional replication of the experiment will be required, thus increasing the minimal size to 4096 observations.

An experiment that uses a $2^{(n-p)}$ subset of the original 2^n measurements is called a $\frac{1}{2}p$ replicate or a $2^{(n-p)}$ Fractional Factorial. This experimental design combines the advantage of reduced experiment size with a corresponding disadvantage of reduced information gained. As will be shown in the following discussion, a well-designed $2^{(n-p)}$ Fractional Factorial can, if certain basic assumptions are satisfied, provide a wealth of information while greatly reducing the size of the experiment.

B. GENERAL CHARACTERISTICS AND NOTATION FOR THE 2^n FACTORIAL

A special notational scheme has been developed for the 2^n Factorial which generalizes directly to the $2^{(n-p)}$ Fractional Factorial. Consider the 2^4 Factorial where the four factors are designated by the upper case letters A, B, C, and D. The 16 treatment combinations of high and low levels of each of the four factors are designated with lower case letters as follows: the presence of a letter indicates the high level of that factor, its absence denotes the low level. The symbol (1) denotes that treatment where all factors are at the low level. Thus the treatment designation bd indicates that factors B and D are at their high levels, while factors A and C are at their low levels. Using this scheme, the treatment combinations for the 2^4 Factorial are as shown in Table II.1.

Table II.1

Treatment Combinations in a 2^4 Factorial

(1)	c	d	cd
a	ac	ad	acd
b	bc	bd	bcd
ab	abc	abd	abcd

It can be shown that in general there are precisely $2^n - 1$ orthogonal contrasts in a 2^n Factorial, each corresponding to a main or interaction effect. A contrast C_m is defined for any linear combination of k treatment totals as follows:

$$C_m = c_{1m}n_1T_{.1} + c_{2m}n_2T_{.2} + \dots + c_{km}n_kT_{.k}$$

where

$$c_{1m}n_1 + c_{2m}n_2 + \dots + c_{km}n_k = 0.$$

In this expression $j = 1,2, \dots, k$ and n_j is the number of observations for treatment$_j$, $T_{.j}$ is the total of the n_j observations for treatment$_j$, and c_{jm} is the contrast coefficient for treatment$_j$. This can be stated more compactly as follows:

$$C_m \text{ is a contrast if } \sum_{j=1}^{k} n_jc_{jm} = 0 .$$

Two contrasts C_m and C_q are orthogonal if

$$\sum_{j=1}^{k} n_j c_{jm} c_{jq} = 0 .$$

An easy way to show how each contrast is estimated and that orthogonality exists in a 2^n Factorial is to assign coefficients of + or - to treatment combinations whose effect being estimated is at a high level or low level respectively. Here $n_1 = n_2 = \ldots = n_k$, and $c_{jm} = +1$ or -1 accordingly. Table II.2 shows such a scheme for the 2^4 Factorial.

It should be noted from Table II.2 that the coefficient of an interaction effect is obtained by taking the product of the coefficients corresponding to the factors that make up the interaction. It can easily be verified from Table II.2 that the coefficients in each row sum to zero and that the vector dot product of any two rows equals zero, thus satisfying the definitions of contrast and orthogonal contrast. Thus the contrast used to estimate the main effect of A in a 2^4 Factorial would be as follows:

$$A_{\text{contrast}} = a + ab + ac + abc + ad + abd + acd + abcd$$
$$- (1) - b - c - bc - d - bd - cd - bcd.$$

Simply stated the contrast for A is the sum of all treatments where A is at its high level minus the sum of all treatments where A is at its low level. It is more convenient to represent this contrast as follows:

TABLE II.2

Definitions of Contrasts in a 2^4 Factorial

Contrasts	Treatments															
	(1)	a	b	ab	c	ac	bc	abc	d	ad	bd	abd	cd	acd	bcd	abcd
A	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+
B	−	−	+	+	−	−	+	+	−	−	+	+	−	−	+	+
C	−	−	−	−	+	+	+	+	−	−	−	−	+	+	+	+
D	−	−	−	−	−	−	−	−	+	+	+	+	+	+	+	+
AB	+	−	−	+	+	−	−	+	+	−	−	+	+	−	−	+
AC	+	−	+	−	−	+	−	+	+	−	+	−	−	+	−	+
AD	+	−	+	−	+	−	+	−	−	+	−	+	−	+	−	+
BC	+	+	−	−	−	−	+	+	+	+	−	−	−	−	+	+
BD	+	+	−	−	+	+	−	−	−	−	+	+	−	−	+	+
CD	+	+	+	+	−	−	−	−	−	−	−	−	+	+	+	+
ABC	−	+	+	−	+	−	−	+	−	+	+	−	+	−	−	+
ABD	−	+	+	−	−	+	+	−	+	−	−	+	+	−	−	+
ACD	−	+	−	+	+	−	+	−	+	−	+	−	−	+	−	+
BCD	−	−	+	+	+	+	−	−	+	+	−	−	−	−	+	+
ABCD	+	−	−	+	−	+	+	−	−	+	+	−	+	−	−	+

$$A_{contrast} = \sum_{i=1}^{n'} A_i(\text{high}) - \sum_{j=1}^{n'} A_j(\text{low}).$$

This expression generalizes directly to any effect in both the 2^n and $2^{(n-p)}$ Factorials.

C. DEVELOPMENT OF THE $2^{(n-p)}$ FRACTIONAL FACTORIAL

The problem now becomes one of choosing a subset from among the original 16 treatment combinations listed in Table II.1 in such a way that worthwhile information can be gained from the measurements made. It should be evident that each contrast listed in Table II.2 defines two subsets of $2^{(4-1)}$ treatments or a $\frac{1}{2}$ replicate of the original 2^4. Choosing any contrast, one subset consists of those eight treatments whose corresponding contrast coefficients are positive and the second subset consists of those eight treatments whose corresponding coefficients are negative. Choosing the contrast ABCD as an example and using the subset consisting of treatments whose corresponding contrast coefficients in Table II.2 are positive would result in a $2^{(4-1)}$ Fractional Factorial where ABCD is a defining contrast. The resulting contrast scheme is shown in Table II.3.

The basic characteristics of the $2^{(n-p)}$ Fractional Factorial can easily be seen by examining Table II.3. First, it is readily apparent that no estimate of the effect of the ABCD interaction exists. This effect which was arbitrarily chosen as the defining contrast has become confounded with

Table II.3 Definitions of Contrasts in the 1/2 Replicate of the 2^4 Factorial

I = ABCD

Contrasts	Treatments							
	(1)	ab	ac	bc	ad	bd	cd	abcd
A	-	+	+	-	+	-	-	+
B	-	+	-	+	-	+	-	+
C	-	-	+	+	-	-	+	+
D	-	-	-	-	+	+	+	+
AB	+	+	-	-	-	-	+	+
AC	+	-	+	-	-	+	-	+
AD	+	-	-	+	+	-	-	+
BC	+	-	-	+	+	-	-	+
BD	+	-	+	-	-	+	-	+
CD	+	+	-	-	-	-	+	+
ABC	-	-	-	-	+	+	+	+
ABD	-	-	+	+	-	-	+	+
ACD	-	+	-	+	-	+	-	+
BCD	-	+	+	-	+	-	-	+
ABCD	+	+	+	+	+	+	+	+

the estimate of the grand average of all observations. The symbol I̲ is normally used to denote the grand average and I = ABCD is called the fundamental identity of our example.

Secondly, the contrasts used to estimate AD and BC are identical, and thus these two effects have become confounded. AD and BC are called aliases since the same contrast is used to estimate both the effects of AD and BC. Further examination of Table II.3 will show that in this $\frac{1}{2}$ fraction every contrast estimates two different effects and thus every effect is aliased with one other effect. Thus A and

BCD are aliases, C and ABD are aliases, AB and CD are aliases, etc.

By selecting any of the remaining contrasts from Table II.3, the same procedure used in developing the $\frac{1}{2}$ fraction will result in a $\frac{1}{4}$ fraction. Choosing the contrast AB and using the subset consisting of treatments whose corresponding contrast coefficients in Table II.3 are positive would result in a $\frac{1}{4}$ replicate or $2^{(4-2)}$ Fractional Factorial where the fundamental identity is I = ABCD = AB = CD. The resulting contrast scheme is shown in Table II.4.

Table II.4 Definitions of Contrasts in the 1/4 Replicate of the 2^4 Factorial

I=ABCD=AB=CD

Contrasts	Treatments			
	(1)	ab	cd	abcd
A	-	+	-	+
B	-	+	-	+
C	-	-	+	+
D	-	-	+	+
AB	+	-	+	+
AC	+	-	-	+
AD	+	-	-	+
BC	+	-	-	+
BD	+	+	-	+
CD	+	-	+	+
ABC	-	-	+	+
ABD	-	+	+	+
ACD	-	+	-	+
BCD	-	+	-	+
ABCD	+	+	+	+

Several generalities of the $2^{(n-p)}$ Fractional Factorial can be realized from examining Table II.4. First, it can easily be seen that the selection of AB as the defining contrast, not only confounds AB with the grand average, but automatically confounds its alias CD with the grand mean, thus CD in this case becomes a defining contrast as well. In general there will be precisely $2^p - 1$ defining contrasts in a $2^{(n-p)}$ Fractional Factorial. Secondly, it can be seen that of the remaining twelve contrasts there are in fact only three unique contrasts, each being used to estimate four different effects, thus every effect is confounded or aliased with three other effects. In general there will be precisely $2^{(n-p)} - 1$ unique contrasts in a $2^{(n-p)}$ Fractional Factorial. Furthermore, each effect in a $2^{(n-p)}$ Fractional Factorial will be aliased with precisely $2^p - 1$ other effects.

It should be noted from the above discussion that there is a direct correlation between the number of defining contrasts and the number of aliases per effect estimated. The fundamental identity I not only lists all effects which are confounded with the grand average but can be used to determine the aliases of any effect in a $2^{(n-p)}$ Fractional Factorial as well. This is accomplished by multiplying the effect by the terms in the fundamental identity modulus 2. Thus in our example, where I=ABCD=AB=CD, the aliases of A could be found as follows:

$$A \cdot ABCD = A^2BCD = BCD$$

$$A \cdot AB = A^2B = B$$

$$A \cdot CD = ACD$$

D. BLOCKING IN A $2^{(n-p)}$ FRACTIONAL FACTORIAL

It is often difficult in large experiments to obtain measurements for every treatment under identical conditions. Blocking is a common technique used to account for this heterogeneity, but its use results in a corresponding loss of additional information. Consider the contrast scheme of the $2^{(4-1)}$ Fractional Factorial shown in Table II.3. Two blocks can easily be formed by selecting any of the unique contrasts remaining and placing those treatments with corresponding positive coefficients in Block 1 and the remaining treatments with corresponding negative coefficients in Block 2. For example, if AB is selected as the defining contrast for blocks, then the resulting plan would be as shown in Table II.5.

Table II.5

$2^{(4-1)}$ Fractional Factorial in
2 Blocks of 4 Units Each

Factors: A,B,C,D

I=ABCD

Block Confounding: AB

Block 1	Block 2
(1)	ac
ab	bc
cd	ad
abcd	bd

It should be evident from examining this plan that AB as well as its alias CD have become confounded with the block effect, and thus these effects can no longer be estimated independent of the block effect. It is important therefore that only effects which can be assumed negligible be selected as defining contrasts for blocking. A four block plan could easily be formed by using a similar technique on the already existing blocks. For example, if A is selected as the defining contrast then the resulting plan would be as shown in Table II.6.

Table II.6

$2^{(4-1)}$ Fractional Factorial Plan
in 4 Blocks of 2 units each

Factors: A,B,C,D

Block Confounding: AB,A,B

Block 1	Block 2	Block 3	Block 4
ab	(1)	ac	bc
abcd	cd	ad	bd

Again it is obvious from observing Table II.6 that A as well as its alias BCD become confounded with the block effect and no clear estimate of either can be obtained. Furthermore it should be noted that B as well as its alias ACD has also become confounded with blocks. Multiplication of the previously chosen defining contrasts for blocks with the newly selected contrast for further blocking modulus 2

will yield the additional effects confounded with blocks. Thus in this example $AB \cdot A = A^2B = B$ is also confounded with blocks. In general if there are k blocks in a $2^{(n-p)}$ Fractional Factorial there will be precisely $(k-1)2^p$ effects confounded with blocks.

E. USEFULNESS OF THE $2^{(n-p)}$ FRACTIONAL FACTORIAL

It should be obvious that the use of the fractional factorial greatly reduces the size of the experiment but also correspondingly reduces the amount of information that can be gained from the experiment. Doubtful use at best could be gained from the $\frac{1}{4}$ replicate shown in Table II.4 since any inference made about a main effect, say A, would require a bold assumption regarding the main effect of its alias, B.

But consider the scheme represented by the $\frac{1}{2}$ replicate shown in Table II.3. Here again any inference made about the main effect of A would require that an assumption be made about its alias, BCD. But in this case this is not nearly so bold an assumption as that required in the $2^{(4-2)}$ scheme shown in Table II.4. In using the $\frac{1}{2}$ replicate shown in Table II.3, a clear estimate of the effect of all main effects can be obtained if an assumption can be made that the effects of 2nd order interaction aliases are insignificant. Thus the main effects are measurable assuming that their aliases are negligible. In general, all effects in a $2^{(n-p)}$ Fractional Factorial are considered measurable if

they are aliased with no less than 2nd order interactions -- 3-factor interactions.

In using the $2^{(n-p)}$ Fractional Factorial the assumption is normally made that higher order interactions are negligible. These assumptions are in general realistic. In most applications main effects are rather more important than 2-factor interactions which in turn are a good deal more important than 3-factor interactions. Higher order interactions normally do not often require consideration [1].

III. THE EXPERIMENT

A. EXPERIMENTAL PLAN

Recall from Chapter I that the primary motivation for this thesis was to investigate and to identify the relative importance of the many factors impacting on the tank commander's target selection process. The ultimate goal of this thesis was to enhance the realism achieved in STAR by developing a realistic target selection model based on and substantiated by current and well-founded empirical data. This motivation greatly influenced the choice of the experimental plan used in the study, specifically one that allowed for the investigation of many factors and one that gave reasonable hope for a well-fitted and useful regression model.

The experimental plan selected for the study was a $2^{(11-4)}$ Fractional Factorial in 8 blocks of 16 treatments each and is shown in Table III.1. The characteristics of this plan made it particularly well-suited for the investigation conducted in this study. These can be summarized as follows:

1. The plan allows for the investigation of 11 unique factors each at two levels while reducing the size of the experiment from 2048 to 128 observations per replication.

2. The alias pattern is such that in the worst case all main effects are aliased with no less than 4-factor interactions

Table III.1

EXPERIMENTAL PLAN: 1/16 REPLICATION OF 11 FACTORS IN 8 BLOCKS OF 16 UNITS EACH. [9]

FACTORS: A,B,C,D,E,F,G,H,J,K,L

I=ABCDJK=ABEFJL=CDEFKL=BCEGJKL=ADEGL=ACFGK=BDFGJ=ABCDEFGH =EFGHJK=CDGHJL=ABGHKL=ADFHJKL=BCFHL=BDEHK=ACEHJ.

BLOCK CONFOUNDING: DEFG, BCFG, BCDE, ACEF, ACDG, ABEG, ABDF.

ALL TWO-FACTOR INTERACTIONS ARE MEASURABLE.

BLOCKS

1	2	3	4
(1)	ABCD	BCEG	ABEF
ABCDEFGH	EFGH	ADFH	CDGH
DEFGJL	ABCEFGJL	BCDFJL	ABDGJL
ABCHJL	DHJL	AEGHJL	CEFHJL
ACEFJK	BDEFJK	ABFGJK	BCJK
BDGHJK	ACGHJK	CDEHJK	ADEFGHJK
ACDGKL	BGKL	ABDEKL	BCDEFGKL
BEFHKL	ACDEFHKL	CFGHKL	AHKL
ABDFJ	CFJ	BHJ	DEJ
CEGHJ	ABDEGHJ	ACDEFGJ	ABCFGHJ
ABEGL	CDEGL	BDEFGHL	FGL
CDFHL	ABFHL	ACL	ABCDEHL
BCDEK	AEK	ABCEFHK	ACDFK
AFGHK	BCDFGHK	DGK	BEGHK
BCFGJKL	ADFGJKL	ABCDGHJKL	ACEGJKL
ADEHJKL	BCEHJKL	EFJKL	BDFHJKL

5	6	7	8
ADEG	CDEF	ACFG	BDFG
BCFH	ABGH	BDEH	ACEH
AFJL	CGJL	ACDEJL	BEJL
BCDEGHJL	ABDEFHJL	BFGHJL	ACDFGHJL
CDFGJK	ADJK	EGJK	ABCDEGJK
ABEHJK	BCEFGHJK	ABCDFHJK	FHJK
CEKL	AEFGKL	DFKL	ABCFKL
ABDFGHKL	BCDHKL	ABCEGHKL	DEGHKL
ACDHJ	ABCEJ	BCDGJ	AGJ
BEFGJ	DFGHJ	AEFHJ	BCDEFHJ
ACEFGHL	ABCDFGL	BCEFL	ADEFL
BDL	EHL	ADGHL	BCGHL
DEFHK	BFK	ABDEFGK	CEFGK
ABCGK	ACDEGHK	CHK	ABDHK
GHJKL	BDEGJKL	ABJKL	CDJKL
ABCDEFJKL	ACFHJKL	CDEFGHJKL	ABEFGHJKL

and all 2-factor interactions are aliased with no less than 3-factor interactions. Additionally several 3-factor interactions are aliased with no less than 4-factor interactions. Thus all main effects, 2-factor interactions, and several 3-factor interactions are measurable if 4-factor and higher order interactions are negligible.

3. The block size of 16 treatments is quite manageable and particularly well-suited to experiments treating individual subjects as blocks. This particular aspect of the plan is discussed in greater detail in the later section dealing with data collection.

4. The factorial structure of the plan allows for the analysis of both main effects and interaction effects.

B. DEPENDENT AND INDEPENDENT VARIABLES

Two dependent variables relating directly to the two primary questions involved in the target selection process were investigated in this study. The first of these variables will be referred to as the threat index, specifically a measure of the degree of threat perceived by the tank commander in each of the unique situations described by the treatment combinations listed in Table III.1. The second variable investigated will be referred to as the fire/no-fire decision index, specifically a measure of the certainty with which a tank commander would choose to engage or not engage in situations described by the treatment combinations listed in Table III.1. These variables will be

described in much greater detail in the subsequent discussion on data collection.

The choice of 11 independent variables, hereafter referred to as factors, reflected the maximum number considered possible given the resources available and the information desired. This decision was based primarily on the desire that numerous replications of the experiment be made to insure the best possible estimate for any given treatment combination. It should be noted here that the consideration of a single additional factor, assuming a similar blocking scheme and a desire for equivalent type information, would have doubled the size of the experiment and thus yielded $\frac{1}{2}$ the number of repetitions per treatment combination that were eventually obtained. The choice of the 11 specific factors that were investigated was the result of much deliberation among several U.S. Army officers familiar with the Armor battlefield. Primary consideration was given to the inclusion of those factors that were thought to be the most relevant in the target selection process.

In the experimental plan shown in Table III.1 and in the remainder of this thesis, factors are designated by the letters: A,B,C,D,E,F,G,H,J,K,L. The factors that were investigated in the study and designated by the letter scheme shown above are as follows:

A -- on board rounds remaining

A_{LOW} -- above critical level

A_{HIGH} -- at or below critical level

B -- friendly tank's current activity

B_{LOW} -- stationary/hull defilade

B_{HIGH} -- moving/partially exposed

C -- anticipated resupply

C_{LOW} -- soon

C_{HIGH} -- not soon

D -- speed of enemy target

D_{LOW} -- not fast

D_{HIGH} -- fast

E -- cover/concealment of the enemy target

E_{LOW} -- fully exposed

E_{HIGH} -- not fully exposed

F -- enemy target's position relative to friendly tank's sector of responsibility

F_{LOW} -- enemy target is not in the sector

F_{HIGH} -- enemy target is in the sector

G -- intelligence on previous firing activity of the enemy target

G_{LOW} -- target has not been detected firing in the last 60 seconds

G_{HIGH} -- target has been detected firing in the last 60 seconds

H -- enemy target type

H_{LOW} -- BMP/BRDM with sagger

H_{HIGH} -- Tank T72

J -- turret orientation of enemy target relative to the friendly tank

J_{LOW} -- turret pointed away from friendly tank

J_{HIGH} -- turret pointed at friendly tank

K -- range to enemy target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

L -- range adjustment factor

L_{LOW} -- no adjustment of range

L_{HIGH} -- add 1300 meters to range

It should be noted that K and L are pseudo factors for range and that four distinct ranges were investigated. Thus the three degrees of freedom attributable to these four levels of range are the main effect of K, the main effect of L, and the interaction of K and L. The four levels of range can easily be explained using the various combinations of K and L as follows:

		Factor L	
		L_{LOW}	L_{HIGH}
Factor K	K_{LOW}	1050 m	2350 m
	K_{HIGH}	1700 m	3000 m

Factor L thus reflects differences between far and near ranges and can be described as follows:

L_{LOW} -- range is less than 2000 meters

L_{HIGH} -- range exceeds 2000 meters

The KL interaction reflects differences between the intermediate ranges and the extreme ranges.

Additional comments are appropriate in regard to the factors listed above. Factors A and C relate directly to the immediate logistical problem faced by a tank commander in combat. Available information indicates that no presently existing combined arms simulation model considers these important logistical questions. It should also be noted that some of the factors are described in subjective terms, factors C and D for example. These somewhat obscure descriptions are considered not unrealistic with the immediate intelligence that would be available to the tank commander on the future high-intensity battlefield.

C. DATA COLLECTION

The absence of existing data at the start of this study required that a major effort be devoted to the collection of such data. This effort was undertaken with the realization in mind that the credibility of eventual conclusions drawn from the study would be directly attributable to the credibility of the data collected for the study. This realization implied the following two fundamental characteristics of the data collection plan:

1. The sampling population should consist of the actual decision makers directly involved with target selection.

2. The data should reflect as much as possible the realistic measurements of the two dependent variables under

investigation, specifically the threat index and the fire/no-fire decision index discussed above. The use of a questionnaire was considered the only feasible approach that would permit the collection of data while still retaining the desired characteristics stated above.

The selection of the experimental plan shown in Table III.1 greatly facilitated the design of the questionnaire used in data collection. It should be evident from observing Table III.1 that each treatment combination fully describes a unique battlefield situation. This fact, coupled with the blocking scheme shown in Table III.1, became the essence of the questionnaire. Eight distinct questionnaires were used in the actual data collection, each corresponding to one of the eight experimental blocks of the experiment. A modified version of the questionnaire corresponding to Block 1 is shown in Appendix A. Each questionnaire was identical to the one shown in Appendix A with the exception that the particular situations presented were uniquely based on the 16 distinct treatment combinations peculiar to the experimental block corresponding to the questionnaire. Additionally, situation 17 of each questionnaire was identical to situation 5 of that particular questionnaire, and situation 18 was a unique situation that was identical for all questionnaires.

Several attributes of the questionnaire are considered deserving of further comment. The introductory comments

that are shown in Appendix A and that characterized each questionnaire reflected a serious attempt to clarify the general nature and terminology of the questionnaire and to familiarize the individual with the specific requirements expected of him in completing the questionnaire. It is important to note that decisive individual action was encouraged by instructing the individual to rapidly appraise each situation and to respond accordingly with minimal hesitation. The restriction of the size of each questionnaire to 18 situations tended to reduce the lack of motivation and lack of interest commonly generated by lengthy questionnaires. The inclusions of situations 17 and 18, as defined above, gave some insight into the consistency of each individual's responses as well as a general consistency among the entire sample of individuals. Additionally, the critique and personal history form greatly facilitated the summarizing of important characteristics of the sample from which the data was collected.

Sixty-four tank commanders presently serving on active duty participated in the study, and thus 8 replications of the experiment were conducted. A summary of the important characteristics of these tank commanders is given in Appendix B. The data base thus established, which became the basis for the analysis discussed in the subsequent portions of this thesis, is shown in Tables III.2 and III.3. Table III.2 reflects observations obtained for response 1, specifically measurements of the threat index standardized

to a 0-1 scale. Table III.3 reflects observations obtained for response 2, specifically measurements of the fire/no-fire decision index. The organization of these tables corresponds directly to the experimental plan shown in Table III.1. It should be noted from Tables III.2 and III.3 that there was in general much disagreement among the tank commanders questioned concerning both the threat posed by a specific enemy target and the decision to engage or not to engage a specific target. The data thus substantiates the very subjective nature of the two dependent variables investigated.

It is the opinion of the author that the data base thus established and discussed above is credible and does provide insight into the relative importance of the factors investigated in the target selection process of the current generation of tank commanders. This opinion is based in part on the extensiveness of the data base and on the generally favorable comments made by the tank commanders who participated in the study. It is acknowledged that numerous physical and psychological factors relevant to actual combat and not directly considered in this study could profoundly alter the naturally judgemental decisions reflected in this data base. Unfortunately, to realistically measure the effect of such factors as stress, fear, fatigue, confusion, etc., is far beyond the capabilities of this study, and would be doubtful at best short of actual combat.

Table III.2 Standardized Observations of Threat Index

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
(1)	1	0.49	0.50	0.75	0.90	0.65	0.54	0.40	0.76
ABCDEFGH	1	0.38	0.80	0.65	0.65	0.85	0.42	0.45	0.65
DEFGJL	1	0.49	0.80	0.35	0.85	0.74	0.52	0.85	0.74
ABCHJL	1	0.68	0.80	0.60	0.55	0.74	0.82	0.85	0.74
ACEFJK	1	0.29	0.80	0.50	0.77	0.84	0.92	0.86	0.83
BDGHJK	1	0.19	1.00	0.80	0.75	0.94	0.82	0.90	0.82
ACDGKL	1	0.68	0.50	0.30	0.35	0.67	0.32	0.44	0.66
BEFHKL	1	0.97	0.60	0.40	0.50	0.57	0.52	0.40	0.64
ABDFJ	1	0.29	0.80	0.80	0.70	0.84	0.92	0.94	0.84
CEGHJ	1	0.28	1.00	0.65	0.75	0.95	1.00	0.90	0.74
ABEGL	1	0.72	0.90	0.45	0.64	0.64	0.52	0.38	0.75
CDFHL	1	0.98	0.71	0.60	0.75	0.63	0.44	0.70	0.67
BCDEK	1	0.77	0.50	0.50	0.75	0.72	0.92	0.34	0.74
AFGHK	1	0.17	0.91	0.60	0.86	0.75	0.94	0.40	0.76
BCFGJKL	1	0.68	0.90	0.40	0.55	0.75	0.62	0.60	0.75
ADEHJKL	1	0.97	0.60	0.70	0.54	0.56	0.62	0.60	0.64
ABCD	2	0.45	0.70	0.83	0.60	0.60	0.52	0.35	0.20
EFGH	2	0.55	0.40	0.55	0.85	0.94	0.54	0.78	0.50
ABCEFGJL	2	0.83	0.60	0.65	0.40	0.86	0.82	0.84	0.60
DHJL	2	0.93	0.70	0.76	0.38	0.74	1.00	0.65	0.74
BDEFJK	2	0.75	0.70	0.73	0.75	0.75	0.91	0.75	0.49
ACGHJK	2	0.95	0.40	0.35	0.90	0.94	0.42	0.84	0.88
BGKL	2	0.45	0.70	0.96	0.28	0.87	0.42	0.64	0.26
ACDEFHKL	2	0.35	0.60	0.66	0.30	0.75	0.72	0.57	0.40
CFJ	2	0.95	0.60	0.25	0.94	0.86	1.00	0.87	0.88
ABDEGHJ	2	0.90	0.40	0.55	0.80	0.96	0.62	0.84	0.90
CDEGL	2	0.45	0.70	0.86	0.43	0.66	0.42	0.74	0.20
ABFHL	2	0.45	0.60	0.74	0.43	0.84	0.54	0.75	0.60
AEK	2	0.35	0.70	0.55	0.54	0.55	0.92	0.75	0.55
BCDFGHK	2	0.55	0.60	0.56	0.75	0.85	1.00	0.75	0.50
ADFGJKL	2	0.75	0.60	0.64	0.28	0.94	0.64	0.65	0.60
BCEHJKL	2	0.35	0.50	0.64	0.56	0.65	0.54	0.65	0.50

Table III.2 (continued)

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
BCEG	3	0.81	0.72	0.82	0.70	0.68	0.72	0.66	0.54
ADFH	3	0.61	0.62	0.91	0.50	0.82	0.56	0.60	0.64
BCDFJL	3	0.95	0.91	0.68	0.80	0.87	0.62	0.90	0.84
AEGHJL	3	0.71	0.82	0.40	0.80	0.92	0.36	0.90	0.82
ABFGJK	3	1.00	1.00	0.75	0.90	0.96	0.63	0.94	0.94
CDEHJK	3	0.81	0.92	0.50	0.70	0.88	0.62	0.74	0.92
ABDEKL	3	0.71	0.62	0.25	0.30	0.52	0.38	0.55	0.44
CFGHKL	3	0.51	0.80	0.30	0.30	0.45	0.45	0.70	0.44
BHJ	3	1.00	1.00	0.90	0.81	0.84	0.84	0.80	0.86
ACDEFGJ	3	1.00	0.81	1.00	0.80	0.95	0.46	0.90	0.94
BDEFGHL	3	0.61	0.72	0.40	0.40	0.67	0.57	0.70	0.64
ACL	3	0.85	0.64	0.26	0.30	0.58	0.45	0.64	0.56
ABCEFHK	3	0.75	0.90	0.44	0.30	0.72	0.64	0.70	0.74
DGK	3	0.91	0.72	0.80	0.30	0.57	0.52	0.74	0.74
ABCDGHJKL	3	0.85	1.00	0.19	0.20	0.88	0.36	0.90	0.74
EFJKL	3	1.00	0.90	0.60	0.51	0.86	0.74	0.90	0.74
ABEF	4	0.62	0.75	0.40	0.86	0.45	0.64	0.55	0.93
CDGH	4	0.45	0.75	0.75	0.92	0.54	0.87	0.65	0.60
ABDGJL	4	0.67	0.65	0.32	0.61	0.84	0.94	0.84	0.76
CEFHJL	4	0.50	0.65	0.51	0.40	0.65	0.74	0.84	0.80
BCJK	4	0.65	0.65	0.65	0.52	0.75	0.44	0.95	0.96
ADEFGHJK	4	0.80	0.75	0.90	0.95	0.84	0.77	0.94	0.98
BCDEFGKL	4	0.40	0.35	0.60	0.20	0.54	0.37	0.44	0.30
AHKL	4	0.40	0.45	0.20	0.20	0.35	0.25	0.44	0.45
DEJ	4	0.60	0.35	0.65	0.80	0.75	0.92	0.85	0.78
ABCFGHJ	4	0.90	0.95	1.00	1.00	0.64	0.90	0.96	1.00
FGL	4	0.59	0.45	0.45	0.70	0.75	0.55	0.63	0.46
ABCDEHL	4	0.50	0.35	0.24	0.30	0.46	0.56	0.56	0.55
ACDFK	4	0.65	0.45	0.52	0.40	0.65	0.65	0.74	0.55
BEGHK	4	0.65	0.55	0.75	0.40	0.54	0.58	0.74	0.80
ACEGJKL	4	0.49	0.55	0.50	0.75	0.74	0.86	0.74	0.20
BDFHJKL	4	0.55	0.35	0.32	0.50	0.74	0.85	0.74	0.40

Table III.2 (continued)

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
ADEG	5	0.51	0.61	0.94	0.65	0.75	0.58	0.62	0.62
BCFH	5	0.80	0.78	0.24	0.64	0.60	0.70	0.54	0.74
AFJL	5	0.80	0.90	0.75	0.86	0.80	0.62	0.63	0.92
BCDEGHJL	5	0.59	0.88	0.20	0.86	0.84	0.75	0.84	0.92
CDFGJK	5	0.70	0.96	0.83	0.86	0.80	0.46	1.00	1.00
ABEHJK	5	0.90	0.99	0.15	0.34	0.90	0.74	0.85	0.92
CEKL	5	0.12	0.55	0.75	0.87	0.50	0.50	0.33	0.26
ABDFGHKL	5	0.10	0.48	0.45	0.85	0.75	0.61	0.65	0.67
ACDHJ	5	0.35	0.96	0.15	0.34	0.98	0.70	0.84	1.00
BEFGJ	5	0.83	0.87	0.14	0.27	0.90	0.60	0.83	1.00
ACEFGHL	5	0.50	0.68	0.35	0.35	0.68	0.51	0.55	0.74
BDL	5	0.60	0.46	0.75	0.75	0.70	0.50	0.67	0.36
DEFHK	5	0.85	0.68	0.54	0.24	0.75	0.74	0.75	0.62
ABCGK	5	0.70	0.68	0.45	0.25	0.70	0.60	0.74	0.36
GHJKL	5	0.76	0.80	0.26	0.75	0.76	0.56	0.64	0.56
ABCDEFJKL	5	0.70	0.90	0.26	0.83	0.75	0.64	0.75	0.82
CDEF	6	0.50	0.65	0.90	0.42	0.60	0.30	0.60	0.72
ABGH	6	0.50	0.15	0.80	0.35	0.70	0.60	0.48	0.85
CGJL	6	0.70	0.75	0.40	0.74	0.69	0.80	0.75	0.84
ABDEFHJL	6	0.60	0.95	0.75	0.83	0.50	0.60	0.73	0.64
ADJK	6	0.80	0.65	0.90	0.84	0.70	0.50	0.75	0.72
BCEFGHJK	6	1.00	0.97	0.74	0.92	1.00	0.60	0.75	0.90
AEFGKL	6	0.30	0.25	0.40	0.15	0.70	0.30	0.58	0.52
BCDHKL	6	0.40	0.15	0.60	0.12	0.40	0.30	0.55	0.10
ABCEJ	6	0.70	0.75	0.70	0.34	0.70	0.60	0.86	0.70
DFGHJ	6	0.90	0.98	0.94	0.94	1.00	0.90	0.98	1.00
ABCDFGL	6	0.80	0.05	0.50	0.44	0.60	0.30	0.60	0.20
EHL	6	0.60	0.35	0.60	0.53	0.50	0.30	0.50	0.10
BFK	6	0.51	0.18	0.81	0.54	0.68	0.30	0.50	0.66
ACDEGHK	6	0.50	0.15	0.60	0.64	0.80	0.40	0.50	0.60
BDEGJKL	6	0.51	0.55	0.60	0.53	0.40	0.60	0.80	0.78
ACFHJKL	6	0.90	0.98	0.61	0.74	0.80	0.60	0.65	0.50

Table III.2 (continued)

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
ACFG	7	0.93	0.55	0.85	0.42	0.65	0.86	0.72	0.65
BDEH	7	0.93	0.30	0.72	0.52	0.85	0.94	0.52	0.56
ACDEJL	7	0.76	0.50	0.57	0.92	0.75	1.00	0.80	0.55
BFGHJL	7	0.95	0.80	0.40	0.94	0.95	0.90	0.65	0.76
EGJK	7	0.85	0.80	0.70	0.92	0.86	0.90	0.82	0.70
ABCDFHJK	7	1.00	0.65	0.55	0.72	0.94	1.00	0.68	0.94
DFKL	7	0.54	0.39	0.17	0.25	0.64	0.80	0.40	0.37
ABCEGHKL	7	0.62	0.25	0.10	0.54	0.75	0.80	0.35	0.45
BCDGJ	7	0.95	0.80	0.38	0.94	0.85	1.00	0.90	0.69
AEFHJ	7	0.95	0.95	0.50	0.94	0.96	1.00	0.92	0.80
BCEFL	7	0.73	0.48	0.50	0.24	0.56	0.90	0.51	0.56
ADGHL	7	0.78	0.60	0.30	0.44	0.64	0.90	0.51	0.57
ABDEFGK	7	0.86	0.70	0.50	0.64	0.64	0.90	0.60	0.70
CHK	7	0.84	0.55	0.60	0.34	0.64	0.90	0.54	0.60
ABJKL	7	0.67	0.49	0.26	0.64	0.85	0.80	0.70	0.80
CDEFGHJKL	7	0.85	0.40	0.22	0.72	0.84	0.90	0.79	0.65
BDFG	8	0.83	0.70	0.78	0.52	0.84	0.46	0.72	0.45
ACEH	8	0.58	0.65	0.78	0.72	0.88	0.36	0.94	0.75
BEJL	8	0.82	0.73	0.45	0.52	0.80	0.26	0.98	0.35
ACDFGHJL	8	0.67	0.95	0.50	0.72	0.98	0.50	0.98	0.86
ABCDEGJK	8	0.95	0.85	0.65	0.42	0.80	0.40	0.74	0.83
FHJK	8	0.88	0.75	0.64	0.22	0.80	0.80	1.00	1.00
ABCFKL	8	0.64	0.45	0.70	0.82	0.50	0.20	0.55	0.25
DEGHKL	8	0.62	0.40	0.50	0.32	0.58	0.30	0.55	0.75
AGJ	8	0.95	0.55	0.70	0.62	0.84	0.81	0.83	0.74
BCDEFHJ	8	0.98	0.75	0.98	0.22	0.74	0.90	0.98	1.00
ADEFL	8	0.82	0.55	0.50	0.72	0.63	0.55	0.45	0.34
BCGHL	8	0.88	0.65	0.50	0.84	0.69	0.44	0.75	1.00
CEFGK	8	0.96	0.50	0.60	0.72	0.65	0.36	0.96	0.55
ABDHK	8	0.92	0.45	0.65	0.52	0.72	0.45	0.65	0.84
CDJKL	8	0.84	0.45	0.70	0.72	0.62	0.30	0.64	0.35
ABEFGHJKL	8	0.87	0.67	0.30	0.52	0.74	0.68	0.85	0.75

Table III.3 Observations of Fire/No-fire Decision Index

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
(1)	1	YES	NO	YES	YES	YES	NO	NO	YES
ABCDEFGH	1	YES	YES	NO	NO	YES	NO	NO	YES
DEFGJL	1	NO	YES	NO	NO	YES	YES	YES	NO
ABCHJL	1	YES	YES	YES	NO	NO	YES	YES	YES
ACEFJK	1	YES	YES	NO	YES	YES	YES	YES	YES
BDGHJK	1	NO	YES	YES	YES	YES	YES	YES	YES
ACDGKL	1	NO	NO	NO	NO	NO	NO	NO	NO
BEFHKL	1	NO	NO	NO	NO	NO	YES	NO	NO
ABDFJ	1	YES	YES	YES	YES	YES	YES	YES	YES
CEGHJ	1	YES	YES	YES	YES	YES	YES	YES	YES
ABEGL	1	YES	YES	NO	NO	NO	YES	NO	NO
CDFHL	1	NO	NO	YES	YES	YES	YES	YES	NO
BCDEK	1	YES	NO	NO	YES	YES	YES	NO	NO
AFGHK	1	YES	YES	YES	YES	YES	YES	YES	YES
BCFGJKL	1	NO	YES	NO	NO	NO	YES	YES	YES
ADEHJKL	1	NO	NO	NO	NO	NO	YES	YES	NO
ABCD	2	NO	NO	NO	YES	NO	NO	NO	NO
EFGH	2	YES	YES	NO	YES	YES	NO	YES	YES
ABCEFGJL	2	NO	NO	NO	NO	YES	YES	NO	YES
DHJL	2	NO	NO	NO	NO	YES	YES	YES	NO
BDEFJK	2	YES	NO	NO	YES	YES	YES	YES	YES
ACGHJK	2	YES	YES	YES	YES	YES	NO	YES	YES
BGKL	2	NO	NO	NO	NO	YES	NO	NO	NO
ACDEFHKL	2	NO	NO	NO	NO	NO	YES	NO	NO
CFJ	2	YES	YES	YES	YES	YES	YES	YES	YES
ABDEGHJ	2	YES	NO	YES	YES	YES	YES	YES	YES
CDEGL	2	NO	NO	NO	NO	YES	YES	NO	NO
ABFHL	2	NO	YES	NO	NO	YES	YES	NO	YES
AEK	2	YES	NO	NO	NO	YES	YES	YES	NO
BCDFGHK	2	YES	NO	YES	YES	YES	YES	YES	YES
ADFGJKL	2	NO	NO	YES	NO	YES	YES	NO	NO
BCEHJKL	2	NO	NO	NO	NO	NO	YES	NO	NO

Table III.3 (continued)

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
BCEG	3	YES	YES	YES	YES	YES	YES	YES	NO
ADFH	3	NO	YES	YES	YES	YES	NO	NO	NO
BCDFJL	3	YES	NO	NO	YES	YES	NO	YES	NO
AEGHJL	3	YES	NO	NO	YES	YES	NO	YES	NO
ABFGJK	3	YES	YES	YES	YES	YES	NO	YES	YES
CDEHJK	3	YES	YES	NO	YES	YES	YES	YES	YES
ABDEKL	3	NO	NO	NO	NO	NO	NO	NO	NO
CFGHKL	3	NO	NO	NO	NO	NO	NO	NO	NO
BHJ	3	YES	YES	YES	YES	YES	YES	YES	YES
ACDEFGJ	3	YES	YES	YES	YES	YES	YES	YES	YES
BDEFGHL	3	NO	NO	NO	YES	NO	NO	NO	NO
ACL	3	NO	NO	NO	NO	NO	NO	NO	NO
ABCEFHK	3	YES	YES	NO	YES	NO	NO	NO	YES
DGK	3	YES	YES	YES	NO	YES	NO	YES	NO
ABCDGHJKL	3	NO	YES	NO	NO	YES	NO	YES	NO
EFJKL	3	YES	NO	NO	NO	YES	NO	YES	NO
ABEF	4	NO	NO	NO	NO	YES	YES	NO	YES
CDGH	4	YES	YES	YES	YES	YES	YES	NO	YES
ABDGJL	4	NO	NO	NO	NO	YES	YES	NO	YES
CEFHJL	4	NO	NO	NO	NO	YES	NO	NO	YES
BCJK	4	YES	NO	NO	YES	YES	NO	YES	YES
ADEFGHJK	4	YES	NO	YES	YES	YES	NO	YES	YES
BCDEFGKL	4	NO	NO	NO	NO	YES	NO	NO	NO
AHKL	4	NO	NO	NO	NO	NO	NO	NO	YES
DEJ	4	YES	NO	NO	YES	YES	YES	YES	YES
ABCFGHJ	4	YES	YES	YES	YES	YES	YES	YES	YES
FGL	4	YES	YES	NO	NO	YES	YES	NO	YES
ABCDEHL	4	NO	NO	NO	NO	NO	NO	NO	NO
ACDFK	4	NO	NO	NO	NO	YES	NO	YES	NO
BEGHK	4	YES	YES	YES	YES	YES	YES	NO	YES
ACEGJKL	4	NO	NO	NO	NO	YES	NO	NO	NO
BDFHJKL	4	NO	NO	NO	NO	YES	YES	NO	YES

Table III.3 (continued)

TREATMENT	BLK #	REPLICATION							
		1	2	3	4	5	6	7	8
ADEG	5	NO	YES	NO	NO	NO	YES	YES	YES
BCFH	5	YES	YES	YES	NO	YES	YES	NO	YES
AFJL	5	YES	YES	NO	NO	NO	YES	NO	YES
BCDEGHJL	5	NO	YES	YES	NO	YES	YES	YES	YES
CDFGJK	5	YES	YES	YES	NO	YES	YES	YES	YES
ABEHJK	5	YES	YES	YES	YES	YES	YES	YES	YES
CEKL	5	NO	NO	NO	NO	NO	NO	NO	NO
ABDFGHKL	5	NO	YES	NO	NO	NO	NO	NO	NO
ACDHJ	5	YES	YES	YES	YES	YES	YES	YES	YES
BEFGJ	5	YES	YES	YES	YES	YES	YES	YES	YES
ACEFGHL	5	NO	YES	NO	NO	NO	YES	NO	NO
BDL	5	NO	YES	YES	NO	YES	YES	YES	YES
DEFHK	5	YES	YES	YES	YES	YES	YES	YES	YES
ABCGK	5	YES	YES	NO	YES	NO	NO	YES	NO
GHJKL	5	NO	YES	YES	NO	NO	NO	YES	YES
ABCDEFJKL	5	NO	YES	YES	NO	NO	YES	NO	NO
CDEF	6	YES	YES	YES	NO	YES	YES	NO	NO
ABGH	6	YES	YES	YES	NO	YES	YES	YES	YES
CGJL	6	YES	YES	NO	YES	YES	YES	YES	YES
ABDEFHJL	6	YES	YES	NO	YES	YES	YES	NO	NO
ADJK	6	YES	YES	YES	YES	YES	YES	YES	YES
BCEFGHJK	6	YES	YES	NO	YES	YES	YES	YES	YES
AEFGKL	6	NO	YES	NO	NO	NO	NO	NO	NO
BCDHKL	6	NO	YES	NO	NO	NO	NO	NO	NO
ABCEJ	6	NO	YES	NO	YES	YES	YES	YES	YES
DFGHJ	6	YES	YES	YES	YES	YES	YES	YES	YES
ABCDFGL	6	YES	NO	NO	NO	YES	YES	NO	NO
EHL	6	YES	YES	NO	NO	YES	NO	NO	NO
BFK	6	YES	YES	YES	YES	YES	YES	NO	YES
ACDEGHK	6	NO	YES	NO	NO	YES	NO	NO	NO
BDEGJKL	6	YES	YES	NO	NO	NO	YES	YES	YES
ACFHJKL	6	YES	YES	YES	YES	NO	YES	NO	NO

Table III.3 (continued)

TREATMENT	BLK #	REPLICATION 1	2	3	4	5	6	7	8
ACFG	7	YES	NO	NO	YES	YES	YES	YES	YES
BDEH	7	YES	NO	YES	YES	YES	YES	NO	YES
ACDEJL	7	NO	NO	NO	NO	YES	YES	YES	NO
BFGHJL	7	YES	YES	NO	YES	YES	YES	YES	YES
EGJK	7	YES	YES	NO	YES	YES	YES	YES	YES
ABCDFHJK	7	YES	YES	NO	YES	YES	YES	YES	YES
DFKL	7	NO	NO	NO	YES	YES	YES	NO	NO
ABCEGHKL	7	NO	NO	NO	NO	YES	NO	NO	NO
BCDGJ	7	YES	YES	NO	YES	YES	YES	YES	YES
AEFHJ	7	YES	YES	YES	YES	YES	YES	YES	YES
BCEFL	7	NO	NO	NO	NO	YES	NO	NO	NO
ADGHL	7	NO	NO	NO	YES	YES	NO	NO	NO
ABDEFGK	7	YES	YES	NO	YES	YES	YES	NO	NO
CHK	7	YES	NO	NO	YES	YES	NO	NO	YES
ABJKL	7	NO	NO	NO	YES	YES	NO	YES	NO
CDEFGHJKL	7	YES	NO	NO	YES	YES	NO	NO	NO
BDFG	8	YES	YES	YES	YES	YES	YES	NO	YES
ACEH	8	NO	NO	YES	YES	YES	YES	YES	NO
BEJL	8	NO	YES	NO	YES	YES	NO	YES	NO
ACDFGHJL	8	NO	YES	NO	NO	YES	YES	YES	YES
ABCDEGJK	8	YES	YES	NO	YES	YES	YES	NO	YES
FHJK	8	YES	YES	YES	YES	YES	YES	YES	YES
ABCFKL	8	NO	NO	NO	NO	NO	NO	NO	NO
DEGHKL	8	NO	YES	NO	NO	YES	NO	NO	YES
AGJ	8	YES	YES	YES	YES	YES	YES	YES	YES
BCDEFHJ	8	YES	YES	YES	YES	YES	YES	YES	YES
ADEFL	8	NO	NO	NO	NO	NO	NO	NO	NO
BCGHL	8	YES	YES	NO	NO	YES	NO	YES	YES
CEFGK	8	YES	YES	YES	NO	YES	YES	YES	NO
ABDHK	8	YES	YES	YES	YES	YES	YES	NO	YES
CDJKL	8	YES	NO	NO	YES	NO	NO	YES	NO
ABEFGHJKL	8	NO	YES	NO	YES	NO	YES	NO	NO

IV. GENERAL METHODOLOGY USED IN THE ANALYSIS

A. GENERAL COMMENTS CONCERNING THE ANALYSIS

The motivation for the analysis was to determine the relative significance of each of the 11 factors investigated in regard to the two dependent variables considered in the study. Accordingly, two separate analyses were conducted. Chapter V discusses the analysis of the threat index, data for which is shown in Table III.2. Chapter VI discusses the analysis of the fire/no-fire decision index, data for which is shown in Table III.3. The emphasis in both Chapters V and VI is to first identify those effects which were found to be significant and then to attempt to explain the significance of each of those effects identified.

The primary statistical tool used in the analysis was the Analysis of Variance (ANOVA), the proper use of which is dependent upon the following three assumptions:

1. Observations are drawn from normally distributed populations.
2. Observations represent random samples from the population.
3. Variances of the populations are equal.

It is assumed that the observations shown in Tables III.2 and III.3 represent a random sample from the current population of tank commanders thus justifying assumption 2 above. The assumption that the observations were drawn from a normally distributed population is equivalent to the

assumption that the errors e_{ij} are normally distributed, since the errors are the only source of variation in the general linear model hypothesized in the ANOVA. Assumption 3 implies that the variances associated with each treatment combination are equal, specifically that the variance of cell_i, i = 1,2, ..., 128, equals σ_e^2 for all i. Accordingly, the following hypotheses were tested relative to assumptions 1 and 3 above:

Assumption 1:

H_o: e_{ij} for all treatment combinations are distributed $N(0,\sigma^2)$

H_1: H_o is false

Test procedure used: Kolmogorov-Smirnov 1-Sample Test

Assumption 3

H_o: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \ldots = \sigma_{128}^2 = \sigma_e^2$

H_1: some σ_j^2 are not equal

Test procedure used: Bartlett's Test for Homogeneity of Variance

The results of these tests are shown in Chapter V.

B. ANOVA TABLES

Various ANOVA tables appear as part of the discussion in the remainder of this thesis. These were generated utilizing two computer programs specifically designed and programmed to analyze experimental designs of the form used in this

study. The listings of these programs are included as the final portion of this thesis. Each of the various ANOVA tables serves a unique purpose and a discussion of these is deemed appropriate.

1. Generalized ANOVA

The generalized ANOVA, an example of which is shown in Table IV.1, gives a broad overview of the entire analysis. The partition of the total degrees of freedom is reflected in this ANOVA. Recall from the discussion presented in Chapter II that in general the total number of orthogonal contrasts in a $2^{(n-p)}$ Fractional Factorial is $2^{(n-p)} - 1$. Furthermore, in a plan consisting of k blocks, precisely k-1 contrasts are confounded with blocks. The experiment described in this thesis has $2^{(11-4)} - 1$ or 127 orthogonal contrasts of which 7 are confounded with blocks, leaving 120 available to estimate various treatment effects. Additionally,

Table IV.1 Example of Generalized ANOVA

SOURCE	SS	DF	MS
MEAN	963.836	1	
BETWEEN BLOCKS & REPS	13.510	63	
REPLICATIONS	3.320	7	
BLOCKS	1.023	7	
RESIDUAL (BETWEEN)	9.167	49	0.187
WITHIN BLOCKS & REPS	53.020	960	
TREATMENTS	21.175	120	
RESIDUAL (WITHIN)	31.844	840	0.038
TOTAL	1030.366	1024	

it should be noted that the variation due to differences between subjects (64 in this case) is accounted for by the 63 degrees of freedom corresponding to the sources between blocks and replications entry in the generalized ANOVA. The remaining 840 degrees of freedom are allocated to the residual (within treatments) and its calculated mean square thus becomes the denominator of the F-ratio used in testing all subsequent ANOVA hypotheses.

2. Treatment ANOVA

The treatment ANOVA, an example of which is shown in Table IV.2, summarizes the testing of main and interaction effects. This ANOVA thus becomes the primary means of identifying those factors and interactions which had a significant effect on the appropriate dependent variable being analyzed. Several important items concerning the source of variation listed in column 1 of the treatment ANOVA are listed in columns 2 - 7.

Table IV.2 Example of Treatment ANOVA

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)
BG	DFJ	1	0.005	0.006	0.155	0.694
BH	CFL DEK	1	0.004	0.005	0.130	0.718

Column 2 identifies all 2-factor interaction and 3-factor interaction aliases of the source shown in column 1.

All higher order interactions are assumed negligible and are thus suppressed in the ANOVA. Column 3 of the ANOVA reflects the single degree of freedom that corresponds to the single unique orthogonal contrast used to estimate the effect of the source listed in column 1. Columns 4 and 5 represent the calculated effect and mean square attributable to the source shown in column 1. In general the effect and sum of squares corresponding to a factor or interaction in a $2^{(n-p)}$ Fractional Factorial is calculated for A as follows:

$$\text{Effect}_A = \frac{A_{\text{contrast}}}{r \cdot 2^{(n-p-1)}}$$

$$\text{Sum of Squares}_A = \frac{A^2_{\text{contrast}}}{r \cdot 2^{(n-p)}}$$

where

r = number of replications of the experiment.

Thus the effect shown in column 4 represents the mean difference between observations where the source of column 1 is at its high level and observations where it is at its low level. The mean square shown in column 5 is equivalent in our particular case to the sum of squares as calculated above and becomes the numerator of the F-ratio used for significance testing. Thus the F-statistic shown in column 6 and calculated as follows,

$$\text{F-statistic (column 6)} = \frac{\text{Source Mean Square (column 4)}}{\text{Residual Mean Square}}$$

will be distributed according to the F distribution with 1 and 840 degrees of freedom. The hypothesis tested in this ANOVA is as follows:

H_o: The effect of the source shown in column 1 is negligible.

H_1: The effect of the source shown in column 1 is significant.

The decision to reject or not to reject the null hypothesis was based on comparing the right-hand tail probability associated with the calculated F-statistic, column 7 of the ANOVA, with the significance level selected for the analysis, specifically .05.

It can be noted from observing the treatment ANOVA (Table V.4) that all 11 main effects and all 55 2-factor interactions were investigated in the analysis. The remaining 54 degrees of freedom were used for testing the significance of various 3-factor interactions. It is important to note from column 2 that the majority of 2-factor interactions are aliased with 3-factor interactions and that the majority of remaining 3-factor interactions are themselves aliased with other 3-factor interactions. In this regard additional tests were conducted as described below and special qualifications were made in all cases where such interactions were found to be significant.

3. ANOVA for Simple Main Effects

The ANOVA for simple main effects, an example of which is shown in Table IV.3, is used to further investigate

Table IV.3 Example of ANOVA for Simple Main Effects

SOURCE	SS	DF	EFFECT	F	P(X.GT.F)
E	0.091	1	-0.019	2.395	0.122
E AT K(0)	0.253	1	-0.044	6.669	0.010
E AT K(1)	0.006	1	0.007	0.155	0.694
K	1.001	1	-0.063	26.414	0.000
K AT E(0)	0.995	1	-0.088	26.239	0.000
K AT E(1)	0.175	1	-0.037	4.605	0.032
EK	0.168	1	0.026	4.430	0.036

and to explain the significance of those 2-factor interactions that were found to be significant in the treatment ANOVA. The nature of this ANOVA corresponds directly to the general nature of interaction between two factors. Specifically, a measurable difference exists which is dependent upon the different levels of the factors involved. Accordingly, this ANOVA reflects a further partitioning of the sum of squares thus allowing for the investigation of the effects of each factor with respect to the specific levels of the other factor.

An example utilizing the contrast scheme of the $\frac{1}{2}$ replicate of the 2^4 factorial, as shown in Table II.3, is presented here to help clarify the point discussed above. If for example we desired to further investigate the significance of the AB interaction, it would be desirable to evaluate the following null hypotheses:

H_o: A Effect = 0 for both levels of B

H_o: B Effect = 0 for both levels of A

Utilizing the contrast scheme represented in Table II.3, the contrast used to estimate the sum of squares attributable to factor A at the low level of factor B (SS_A at B_{LOW}) is calculated as follows:

$$A_{contrast} \text{ at } B_{LOW} = ac + ad - (1) - cd$$

$$= \sum_{i=1}^{2} A_i(\text{high})B_{LOW} - \sum_{j=1}^{2} A_j(\text{low})B_{LOW} ,$$

and the sum of squares attributable to A at B_{LOW} is thus calculated as:

$$SS_A \text{ at } B_{LOW} = \frac{(A_{contrast} \text{ at } B_{LOW})^2}{4} .$$

The effect of A at B_{LOW}, which is called a simple main effect, represents the mean difference between observations where A is at its high level and B at its low level versus observations where A and B are both at their low levels. Thus the effect of A at B_{LOW} is calculated as follows:

$$\text{Effect}_A \text{ at } B_{LOW} = \frac{A_{contrast} \text{ at } B_{LOW}}{2} .$$

The calculations described above generalize directly to any $2^{(n-p)}$ Fractional Factorial thus implying the following:

$$\text{Simple Main Effect}_{A \text{ at } B_i} = \frac{A_{\text{contrast}} \text{ at } B_i}{r \cdot 2^{(n-p-2)}}, \quad i = 1,2$$

$$\text{Sum of Squares}_{A \text{ at } B_i} = \frac{(A_{\text{contrast}} \text{ at } B_i)^2}{r \cdot 2^{(n-p-1)}}, \quad i = 1,2$$

An F-statistic can be formed by dividing the sum of squares thus calculated, equivalent in this case to the mean square, by the residual mean square. The F-statistic thus formed is distributed according to the F distribution with 1 and 840 degrees of freedom and is used in testing the simple hypotheses stated above.

In conducting tests of hypotheses of simple main effects, it can be shown that SS_A at B_{LOW} + SS_A at B_{HIGH} equals $SS_A + SS_{AB}$, thus each simple main-effects sum of squares contains a portion of the corresponding interaction sum of squares. The procedure recommended for such tests [5] and which was used in the analysis discussed in Chapters V and VI is to assign the same per-family significance level to these tests as that which was used in testing main effects and interactions. Accordingly, a significance level of .025 was used in the analysis.

Further insight into the significance of simple main effects can be gained by examining the individual cell means corresponding to the various levels of the two factors comprising the interaction. These cell means are included as an integral part of the discussion presented in Chapter V.

All previous discussion regarding the definition and computation of main effects, interaction effects, and simple main effects, can be verified by comparing the effects listed in column 4 of the ANOVA with the previously defined linear combinations of the appropriate cell means.

The reader is cautioned that tests for simple main effects are based on non-orthogonal contrasts and thus are not independent. A simple example is provided to clarify this point. Consider the 2-factor interaction AB where the cell means for the various levels would be represented as follows:

		B	
		LOW	HIGH
A	LOW	$\overline{A_{LOW}B_{LOW}}$	$\overline{A_{LOW}B_{HIGH}}$
	HIGH	$\overline{A_{HIGH}B_{LOW}}$	$\overline{A_{HIGH}B_{HIGH}}$

As previously discussed, the effect of A at the low level of B would be calculated as $\overline{A_{HIGH}B_{LOW}} - \overline{A_{LOW}B_{LOW}}$. Similarly, the effect of B at the high level of A would be calculated as $\overline{A_{HIGH}B_{HIGH}} - \overline{A_{HIGH}B_{LOW}}$. It should be obvious that a very large cell mean associated with the $A_{HIGH}B_{LOW}$ cell would almost certainly imply the significance of both simple effects A at B_{LOW} and B at A_{HIGH}, thus reflecting the lack of independence.

4. ANOVA for Simple Simple Main and Simple Interaction Effects

The ANOVA for simple simple main and simple interaction effects, an example of which is shown in Table IV.4, is a direct generalization of the ANOVA for simple main effects discussed above. This ANOVA is used to further investigate and to explain the significance of those 3-factor interactions that were found to be significant in the treatment ANOVA.

Table IV.4 Example

ANOVA for Simple Simple Main & Simple Interaction Effects

SOURCE	SS	DF	EFFECT	F	P(X.GT.F)
A	0.024	1	-0.010	0.0634	0.4261
A at DK(00)	0.039	1	0.025	1.026	0.3115
A at DK(01)	0.057	1	-0.030	1.494	0.2220
A at DK(10)	0.225	1	-0.059	5.945	0.0150
A at DK(11)	0.042	1	0.026	1.113	0.2917

The nature of this ANOVA corresponds directly to the general nature of interaction among three factors, however this is much more complex and much more difficult to explain than interaction between two factors. Interaction among three factors can be attributed to one or both of the following:

1. A marked effect exists for one or more of the factors which depends on the specific levels of the remaining two factors.

2. The interaction between two of the factors depends on the specific level of the third factor.

The general nature of the 3-factor interaction described above makes it desirable that tests of the following type hypotheses be conducted when a significant 3-factor interaction is encountered:

1. H_o: The effect of A is negligible for all combinations of levels of B and C.
2. H_o: The interaction of A and B is negligible for all levels of C.

The ANOVA for simple simple main and simple interaction effects reflects a further partitioning of the sum of squares and thus allows for the testing of the above hypotheses.

An example utilizing the contrast scheme of the $\frac{1}{2}$ replicate of the 2^4 factorial, as shown in Table II.3, is presented to clarify the nature of the ANOVA. If for example we desired to further analyze the significance of the ABC interaction, we could begin by investigating the effect of A with respect to the various combinations of levels of B and C, the four possible combinations being $B_{LOW}C_{LOW}$, $B_{LOW}C_{HIGH}$, $B_{HIGH}C_{LOW}$, and $B_{HIGH}C_{HIGH}$. From Table II.3 the contrast used to estimate the effect of A when both B and C are at their low levels would be as follows:

$$A_{contrast} \text{ at } B_{LOW}C_{LOW} = ad - (1)$$

$$= \sum_{i=1}^{1} A_i(\text{high})B_{LOW}C_{LOW} - \sum_{j=1}^{1} A_j(\text{low})B_{LOW}C_{LOW} ,$$

and the sum of squares attributable to A when both B and C are at their low levels is thus calculated as:

$$SS_A \text{ at } B_{LOW}C_{LOW} = \frac{(A_{contrast} \text{ at } B_{LOW}C_{LOW})^2}{2} .$$

The effect of A at $B_{LOW}C_{LOW}$, which is called a simple simple main effect, reflects the mean difference between observations where A is at its high level and B and C are at their low levels versus observations where A is at its low level and B and C are at their low levels. Thus in this elementary case the simple simple main effect of A at $B_{LOW}C_{LOW}$ would be identical to the $A_{contrast}$ at $B_{LOW}C_{LOW}$. A similar procedure would then be used to compute the 3 remaining simple simple main effects of A at $B_{LOW}C_{HIGH}$, $B_{HIGH}C_{LOW}$, and $B_{HIGH}C_{HIGH}$. Additionally, the simple simple main effects of B with respect to all combinations of A and C and of C with respect to all combinations of A and B could be similarly computed. The resulting sum of squares when divided by the previously calculated residual mean square would form an F-statistic which could be used in testing hypothesis 1.

A similar type computation is required to test hypothesis 2. If for example we desired to investigate the interaction of A and B with respect to the low level of C, we would calculate the contrast from Table II.3 as follows:

$$AB_{\text{contrast}} \text{ at } C_{LOW} = (1) + ab - ad - bd$$

$$= \sum_{i=1}^{2} AB_i(\text{high})C_{LOW} - \sum_{j=1}^{2} AB_j(\text{low})C_{LOW} ,$$

and the corresponding sum of squares would become

$$SS_{AB} \text{ at } C_{LOW} = \frac{(AB_{\text{contrast}} \text{ at } C_{LOW})^2}{4} .$$

The effect of the AB interaction at the low level of C, which is called a simple interaction effect, would be calculated as

$$\text{Effect}_{AB} \text{ at } C_{LOW} = \frac{AB_{\text{contrast}} \text{ at } C_{LOW}}{2} .$$

The sum of squares attributable to this simple interaction effect and as calculated above, divided by the residual mean square, thus forms an F-statistic which can be used for testing hypothesis 2.

The calculations described above generalize directly to any $2^{(n-p)}$ Fractional Factorial thus implying the following:

$$\text{Simple Simple Main Effect}_A \text{ at } B_iC_j = \frac{A_{\text{contrast}} \text{ at } B_iC_j}{r.2^{(n-p-3)}}$$

$$i = 1,2$$
$$j = 1,2$$

$$\text{Sum of Squares}_A \text{ at } B_iC_j = \frac{(A_{\text{contrast}} \text{ at } B_iC_j)^2}{r \cdot 2^{(n-p-2)}},$$

$$i = 1,2$$
$$j = 1,2$$

An F-statistic can be formed by dividing the sum of squares thus calculated, equivalent in this case to the mean square, by the residual mean square. In our analysis the F-statistic thus calculated will be distributed according to the F distribution with 1 and 840 degrees of freedom and can be used to test hypothesis 1.

The calculations described above which were performed in order to test for significance of simple interaction effects also generalize directly to any $2^{(n-p)}$ Fractional Factorial, thus implying the following:

$$\text{Simple Interaction Effect}_{AB} \text{ at } C_i = \frac{AB_{\text{contrast}} \text{ at } C_i}{r \cdot 2^{(n-p-2)}}, \quad i = 1,2$$

$$\text{Sum of Squares}_{AB} \text{ at } C_i = \frac{(AB_{\text{contrast}} \text{ at } C_i)^2}{r \cdot 2^{(n-p-1)}}, \quad i = 1,2$$

In our analysis the F-statistic formed by dividing the sum of squares thus calculated, equivalent in this case to the mean square, by the residual mean square, will be distributed according to the F distribution with 1 and 840 degrees of freedom and can be used to test hypothesis 2.

In conducting tests of hypotheses involving simple simple main effects and simple interaction effects, it can be shown [5] that

$$\sum_{i=1}^{2} \sum_{j=1}^{2} SS_A \text{ at } B_iC_j = SS_A + SS_{AB} + SS_{AC} + SS_{ABC} ,$$

and that

$$\sum_{i=1}^{2} SS_{AB} \text{ at } C_i = SS_{AB} + SS_{ABC} .$$

An argument similar to the one previously mentioned in the discussion of the ANOVA for simple main effects is appropriate for this ANOVA, and accordingly, the significance levels used in the ANOVA were .025 for simple interaction effects and .0125 for simple simple main effects.

Further insight into the significance of simple simple main effects and simple interaction effects can be gained by examining the individual cell means corresponding to the various levels of the three factors comprising the interaction. These cell means are included as an integral part of the discussion presented in Chapter V. All previous discussion regarding the definition and computation of main effects, interaction effects, simple simple main effects, and simple interaction effects, can be verified by comparing

the effects listed in column 4 of the ANOVA with previously defined linear combinations of the appropriate cell means.

The reader is cautioned that tests for simple simple main effects and simple interaction effects are based on non-orthogonal contrasts and thus are not independent. A similar argument as that given previously in the discussion of the ANOVA for simple main effects can be given here. Specifically, an exceptionally large cell mean will in general imply the significance of two or more simple simple main effects or simple interaction effects.

5. Statistics for Selected Model

The computer program utilized in generating the generalized ANOVA and treatment ANOVA also generates a best-fit regression model based on a forward stepwise algorithm. The statistics for the model selected, an example of which is shown in Table IV.5, thus summarize the results of the significance testing conducted in the treatment ANOVA. It should be noted that the regression coefficient shown in column 2 of this table equals $\frac{1}{2}$ the effect shown in column 4 of the treatment ANOVA, and additionally, columns 3-6 coincide directly with the appropriately labeled columns of the treatment ANOVA.

Table IV.5 Example of Statistics for Selected Model

VARIABLE	REGRESSION COEFFICIENT	SUM OF SQUARES	DF	F STATISTIC	PROB (X.GT.F)
F	0.02410	0.595	1	15.694	0.0001
ADK	0.01743	0.311	1	8.204	0.0043

6. General ANOVA for Selected Model

The general ANOVA for Selected Model, an example of which is shown in Table IV.6, is a direct consequence of the selected regression model discussed above. It should be noted that the sum of squares due to regression reflects that portion of the total treatment sum of squares attributable to the factors and interactions that were found to be significant in the treatment ANOVA. Similarly, the sum of squares due to lack of fit reflects the total sum of squares attributable to all remaining factors and interactions. Thus it follows that $SS_{\text{treatments}} = SS_{\text{regression}} + SS_{\text{lack of fit}}$. Accordingly, the F-statistics formed by dividing the mean squares attributable to regression and Lack of Fit and as reflected in column 5 of the ANOVA can be used for testing the significance of regression and lack of fit in regard to the specific model selected.

Table IV.6 Example of General ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F STATISTIC	PROB (X.GT.F)
MEAN	963.836	1	936.836		
REGRESSION(TERMS)	18.184	12	1.515	39.972	0.0000
RESIDUAL	48.346	1011			
LACK OF FIT	2.991	108	0.028	0.731	0.9796
SOURCES(BETWEEN)	13.510	63			
ERROR(ADJUSTED)	31.844	840	0.038		
TOTAL	1030.366	1024			

Various additional information is also included with the ANOVA shown in Chapter VII (Table VII.2). The percent variability that can be explained by regression gives an indication of the relative dispersion of observations within each cell, a small percentage reflecting widely dispersed data. The percent variability explained by the selected model and the sample multiple correlation coefficient give an indication of the total variability that can be accounted for by the selected regression model. Various statistics concerning residuals are also provided, where residuals as discussed here refer to the differences between the mean of observations within each cell and the predicted values as calculated by the model.

V. ANALYSIS OF FACTORS RELEVANT TO THE THREAT INDEX

A. GENERAL COMMENTS CONCERNING THE ANALYSIS

The purpose of the analysis discussed in this chapter was to provide insight into the relative importance of each of the 11 factors investigated with respect to the tank commander's assessment of the immediate threat posed by a target on the battlefield. The analysis of variance (ANOVA) was the primary statistical tool used in the analysis, and all ANOVA tables generated in the study are included in this chapter. The discussion presented in this chapter is limited to those factors and interactions which were found to be significant at the selected significance level of .05. In this respect, it is acknowledged that a great deal of additional information is available to the interested reader who chooses to further examine the ANOVA tables.

It can be recalled from Chapter III that the data base used in this analysis and shown in Table III.2 consists of 1024 observations gathered from 64 different tank commanders. The subjective nature of the observations and specifically the inherent possibility of significant scaling differences among the tank commanders surveyed implied that sensitivity analysis be performed. Accordingly, an analysis similar to the one discussed in the subsequent portions of this chapter was repeated several times, each based on a unique transformation applied to the data base. These transformations included the following:

1. $y' = \sqrt{y}$
2. $y' = y^2$
3. $y' = \ln_e y$
4. $y' = \text{arcsine} \sqrt{y}$

Additionally, the following two transformations were used to test the sensitivity of the data with respect to possible scaling differences among individual tank commanders:

5. $$y_{i,\text{block}_j}' = \frac{y_{i,\text{block}_j} - y_{\text{minimum}_{\text{block}_j}}}{\text{RANGE}_{\text{block}_j}}$$

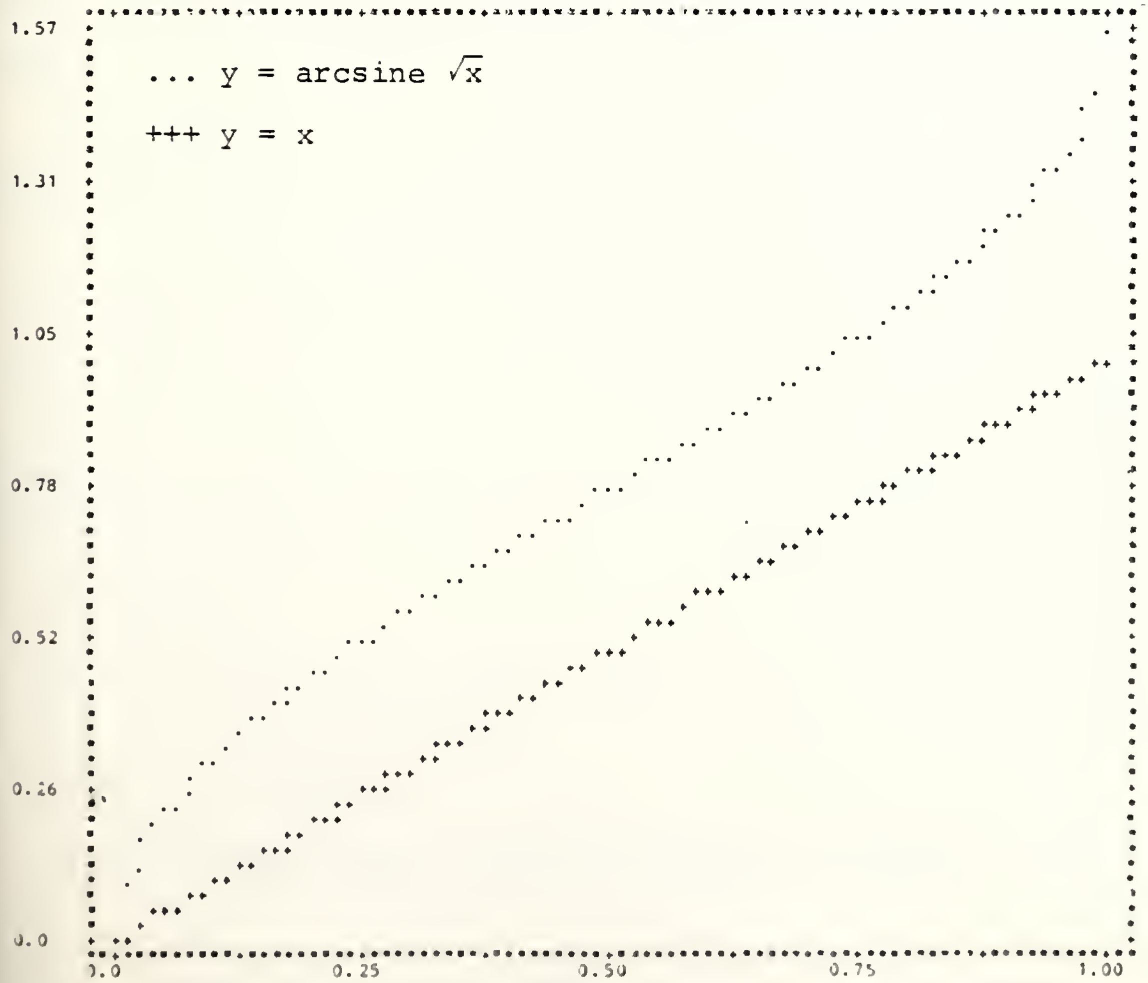
6. $$y_{i,\text{block}_j}' = \frac{y_{i,\text{block}_j} - \bar{y}_{\text{block}_j}}{s_{\text{block}_j}}$$

where j = 1,2,3,... , = 64 refers to each of the 64 distinct blocks of 16 observations corresponding to each of the 64 individual tank commanders; and i = 1,2,3,... , = 16 refers to the 16 observatins peculiar to each particular block_j. It can easily be seen that transformations 5 and 6 are themselves scaled relative to each tank commander and thus tend to equalize differences in scaling that might exist relative to each individual. Transformation 5 causes the minimum observation for each individual to be set to zero and scales the remaining 15 observations from a minimum of zero to a maximum of one, depending on the specific range of the 16 observations peculiar to the individual. Transformation

6 scales the 16 observations peculiar to each individual from a minimum of about -2 to a maximum of about +2.

The analysis discussed in the subsequent portions of this chapter is based on data transformed by the inverse sine transformation, specifically $y' = \text{arcsine}\ \sqrt{y}$, where each y is an observation of the raw data shown in Table III.2. The selection of this transformation was based solely on the fact that the characteristics of the data thus transformed favorably agreed with the assumptions required in the ANOVA. The impact of this transformation, as reflected in Table V.1, is to add increasingly more weight to those observations reflecting a higher assessment of threat.

Table V.1 Plot of $y' = \text{arcsine}\ \sqrt{y}$



A comparison of the treatment ANOVA based on the raw data and the treatment ANOVA's resulting from each of the six transformations discussed above greatly substantiated the conclusions discussed in the remainder of this chapter. Those factors and interactions which are identified in the treatment ANOVA in this chapter as being significant at the .01 level were similarly identified in all treatment ANOVA's regardless of the transformations used. Additionally, the remaining factors and interactions which are identified in this chapter as being significant at the .05 level were in the majority of cases similarly identified, and would have been identified in all cases at the significance level of .06. These results tend to increase the level of confidence associated with the conclusions discussed in this chapter.

Two assumptions that are required in the proper use of the ANOVA are the following:

1. Observations are drawn from normally distributed populations.
2. Variances of the populations are equal.

Accordingly the following hypotheses were tested relative to these assumptions:

Assumption 1:

H_o: e_{ij} for all treatment combinations are distributed $N(0,\sigma^2)$.

H_1: H_o is false.

Test procedure used: Kolmogorov-Smirnov 1-Sample Test

Assumption 2:

H_o: $\sigma_1{}^2 = \sigma_2{}^2 = \sigma_3{}^2 = \ldots = \sigma_{128}{}^2 = \sigma_e{}^2$.

H_1: some $\sigma_j{}^2$ are not equal.

Test procedure used: Bartlett's Test for Homogeneity of Variance.

The results of these tests are shown in Table V.2. The criteria for rejection of the null hypothesis in either of the tests is as follows: Reject the null hypothesis if the right hand tail probability associated with the calculated test statistic is less than the selected significance level of .05. Since the calculated probabilities associated with the test statistics were greater than .05, the null hypotheses as stated above were accepted, thus substantiating the use of the ANOVA in the analysis.

Table V.2

```
********************************************
* STATISTICS FOR TESTING ANOVA ASSUMPTIONS *
********************************************


BARTLETT TEST FOR HOMOGENEITY OF CELL VARIANCES
-----------------------------------------------
      M / C  (CHI SQUARE) :      144.3443
      DEGREES OF FREEDOM :          127
      PROB( X .GT. M/C ) :    0.138993

KS TEST FOR NORMALITY ASSUMPTION
--------------------------------
      KS STATISTIC (DMAX) :  0.053600
      NUMBER OF POINTS :    128
      PROB( X .GT. KS ) :  0.855580
```

B. IDENTIFICATION OF SIGNIFICANT FACTORS AND INTERACTIONS

The total partition of the sum of squares associated with the transformed data is reflected in the generalized ANOVA shown in Table V.3. The residual (within) mean square reflected in this ANOVA, specifically .038, became the denominator in all F-statistics used in the analysis. Furthermore, the 840 degrees of freedom allocated to the residual mean square as shown in Table V.3, appropriately identified the particular distribution of the F-statistics thus calculated.

Table V.3

GENERALIZED ANOVA

SOURCE	SS	DF	MS
MEAN	963.836	1	
BETWEEN BLOCKS & REPS	13.510	63	
REPLICATIONS	3.320	7	
BLOCKS	1.023	7	
RESIDUAL(BETWEEN)	9.167	49	0.187
WITHIN BLOCKS & REPS	53.020	960	
TREATMENTS	21.175	120	
RESIDUAL(WITHIN)	31.844	840	0.038
TOTAL	1030.366	1024	

The treatment ANOVA shown in Table V.4 reflects the investigation of 120 various treatment effects, of which

Table V.4

TREATMENT ANOVA

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)
A	NONE	1	-0.010	0.024	0.634	0.426
B	NONE	1	-0.007	0.011	0.286	0.593
C	NONE	1	-0.004	0.004	0.101	0.751
D	NONE	1	-0.006	0.008	0.209	0.648
E	NONE	1	-0.019	0.091	2.395	0.122
F	NONE	1	0.048	0.595	15.694	0.000 **
G	NONE	1	0.031	0.247	6.514	0.011 *
H	NONE	1	0.031	0.247	6.521	0.011 *
J	NONE	1	0.192	9.483	250.152	0.000 **
K	NONE	1	-0.063	1.001	26.415	0.000 **
L	NONE	1	-0.134	4.594	121.174	0.000 **
AB	NONE	1	-0.003	0.002	0.053	0.818
AC	FGK EHJ	1	-0.009	0.022	0.582	0.446
AD	EGL	1	-0.007	0.013	0.344	0.558
AE	DGL CHJ	1	0.014	0.049	1.292	0.256
AF	CGK	1	0.024	0.144	3.805	0.051
AG	DEL CFK	1	-0.019	0.089	2.351	0.126
AH	CEJ	1	-0.005	0.007	0.133	0.669
AJ	CEH	1	0.015	0.058	1.520	0.218
AK	CFG	1	0.008	0.015	0.396	0.529
AL	DEG	1	0.010	0.024	0.624	0.430
BC	FHL	1	-0.003	0.002	0.056	0.814
BD	FGJ EHK	1	-0.021	0.118	3.101	0.079
BE	DHK	1	-0.010	0.028	0.738	0.391
BF	DGJ CHL	1	-0.008	0.017	0.441	0.507

* INDICATES THAT P(X.GT.F) IS LESS THAN .05
** INDICATES THAT P(X.GT.F) IS LESS THAN .01

Table V.4 (continued)

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)	
BG	DFJ	1	0.005	0.006	0.155	0.694	
BH	CFL DEK	1	0.004	0.005	0.130	0.718	
BJ	DFG	1	-0.006	0.008	0.222	0.638	
BK	DEH	1	0.008	0.015	0.385	0.535	
BL	CFH	1	0.004	0.004	0.099	0.754	
CD	NONE	1	-0.004	0.003	0.084	0.772	
CE	AHJ	1	-0.001	0.000	0.007	0.934	
CF	AGK BHL	1	0.011	0.029	0.776	0.379	
CG	AFK	1	0.003	0.002	0.047	0.829	
CH	BFL AEJ	1	0.001	0.000	0.010	0.920	
CJ	AEH	1	0.007	0.014	0.368	0.545	
CK	AFG	1	-0.015	0.060	1.581	0.209	
CL	BFH	1	-0.003	0.002	0.060	0.806	
DE	AGL BHK	1	0.000	0.000	0.001	0.982	
DF	BGJ	1	-0.005	0.006	0.147	0.701	
DG	AEL BFJ	1	0.001	0.000	0.007	0.934	
DH	BEK	1	0.006	0.009	0.232	0.630	
DK	BEH	1	-0.001	0.000	0.011	0.917	
DJ	BFG	1	0.005	0.005	0.142	0.707	
DL	AEG	1	-0.003	0.003	0.079	0.779	
EF	NONE	1	-0.009	0.022	0.575	0.448	
EG	ADL	1	-0.019	0.095	2.493	0.115	
EH	BDK ACJ	1	-0.011	0.032	0.851	0.357	
EJ	ACH	1	-0.020	0.105	2.761	0.097	
EK	BDH	1	0.026	0.168	4.430	0.036	*
EL	ADG	1	-0.004	0.004	0.105	0.747	

* INDICATES THAT P(X.GT.F) IS LESS THAN .05
** INDICATES THAT P(X.GT.F) IS LESS THAN .01

Table V.4 (continued)

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)	
FG	ACK BDJ	1	-0.008	0.016	0.419	0.517	
FH	BCL	1	0.023	0.134	3.527	0.061	
FJ	BDG	1	0.030	0.231	6.034	0.014	*
FK	ACG	1	0.012	0.034	0.906	0.341	
FL	BCH	1	-0.013	0.046	1.206	0.273	
GH	NONE	1	0.009	0.020	0.536	0.464	
GJ	BDF	1	0.001	0.000	0.006	0.941	
GK	ACF	1	0.004	0.004	0.106	0.745	
GL	ADE	1	-0.015	0.059	1.561	0.212	
HJ	ACE	1	0.011	0.033	0.874	0.350	
HK	BDE	1	-0.015	0.059	1.550	0.213	
HL	BCF	1	-0.017	0.076	2.007	0.157	
JK	NONE	1	-0.006	0.008	0.210	0.647	
JL	NONE	1	-0.015	0.055	1.455	0.228	
KL	NONE	1	-0.032	0.257	6.778	0.009	**
ABC	DJK	1	-0.017	0.071	1.875	0.171	
ABD	CJK	1	-0.003	0.003	0.069	0.793	
ABE	FJL	1	-0.016	0.064	1.683	0.195	
ABF	EJL	1	0.013	0.045	1.177	0.278	
ABG	HKL	1	0.003	0.002	0.044	0.834	
ABH	GKL	1	-0.008	0.018	0.487	0.485	
ABJ	CDK EFL	1	0.009	0.021	0.545	0.461	
ABL	EFJ GHK	1	-0.003	0.003	0.078	0.780	
ACD	BJK	1	-0.008	0.015	0.408	0.523	
ACL	NONE	1	0.016	0.068	1.792	0.181	
ADF	NONE	1	-0.012	0.038	1.008	0.316	
ADH	NONE	1	-0.008	0.016	0.419	0.518	
ADJ	BCK	1	0.001	0.000	0.003	0.959	

* INDICATES THAT P(X.GT.F) IS LESS THAN .05
** INDICATES THAT P(X.GT.F) IS LESS THAN .01

Table V.4 (continued)

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)	
ADK	BCJ	1	0.035	0.311	8.204	0.004	**
AEF	BJL	1	-0.010	0.027	0.704	0.402	
AEK	NONE	1	-0.040	0.409	10.787	0.001	**
AFH	NONE	1	0.005	0.006	0.162	0.687	
AFJ	BEL	1	-0.004	0.003	0.084	0.772	
AGH	BKL	1	-0.014	0.047	1.240	0.266	
AHK	BGL	1	0.015	0.059	1.544	0.214	
AHL	BGK	1	0.011	0.032	0.855	0.355	
AJK	BCD	1	0.001	0.000	0.011	0.916	
AJL	BEF	1	0.012	0.039	1.024	0.312	
AKL	BGH	1	0.007	0.011	0.297	0.586	
BCE	NONE	1	0.007	0.013	0.331	0.565	
BCG	NONE	1	0.005	0.006	0.145	0.703	
BEG	NONE	1	-0.006	0.009	0.246	0.620	
BFK	NONE	1	0.012	0.038	0.991	0.320	
BHJ	NONE	1	0.004	0.005	0.134	0.715	
CDE	FKL	1	0.003	0.002	0.058	0.810	
CDF	EKL	1	0.019	0.088	2.314	0.129	
CDG	HJL	1	-0.023	0.135	3.563	0.059	
CDH	GJL	1	-0.021	0.116	3.063	0.080	
CDL	EFK GHJ	1	0.009	0.019	0.507	0.477	
CEF	DKL	1	-0.011	0.029	0.765	0.382	
CEG	NONE	1	0.005	0.008	0.202	0.654	
CEK	DFL	1	-0.010	0.025	0.650	0.420	
CFJ	NONE	1	0.006	0.010	0.275	0.600	
CGH	DJL	1	0.008	0.016	0.425	0.515	
CGJ	DHL	1	0.010	0.026	0.637	0.407	
CGL	DHJ	1	-0.008	0.015	0.408	0.523	
CJL	DGH	1	0.003	0.002	0.045	0.832	

* INDICATES THAT P(X.GT.F) IS LESS THAN .05
** INDICATES THAT P(X.GT.F) IS LESS THAN .01

Table V.4 (continued)

SOURCE	2/3 FI ALIAS	DF	EFFECT	MEAN SQUARE	F STATISTIC	PROB (X.GT.F)	
CKL	DEF	1	0.003	0.003	0.068	0.794	
DEJ	NONE	1	0.009	0.019	0.512	0.475	
DFH	NONE	1	0.004	0.003	0.084	0.772	
DGK	NONE	1	0.005	0.007	0.177	0.674	
EFG	HJK	1	-0.013	0.045	1.183	0.277	
EFH	GJK	1	0.002	0.001	0.036	0.849	
EGH	FJK	1	-0.001	0.000	0.003	0.961	
EGJ	FHK	1	0.007	0.013	0.345	0.557	
EHL	NONE	1	0.000	0.000	0.000	1.000	
EJK	FGH	1	0.010	0.027	0.712	0.399	
FGL	NONE	1	-0.050	0.641	16.914	0.000	**
JKL	NONE	1	0.010	0.025	0.665	0.415	

* INDICATES THAT P(X.GT.F) IS LESS THAN .05

** INDICATES THAT P(X.GT.F) IS LESS THAN .01

12 were identified as being significant at the .05 level; specifically, the main effects F,G,H,J,K, and L; the 2-factor interactions EK, FJ, and KL; and the 3-factor interactions ADK, AEK, and FGL. It should be noted that the total sum of squares attributable to these 12 effects accounts for 86 percent of the total treatment sum of squares. A reordering of the effects based on their relative importance, as indicated by a comparison of their corresponding sums of squares, is as follows: J,L,K,FGL,F,AEK,ADK,KL,H,G,FJ, and EK.

The remaining portion of this chapter is devoted to the physical interpretation of the factors and interactions that were identified as being significant in the treatment ANOVA. In this respect it is important to note that the effects listed in column 4 of Table V.4 are in some cases positive and in other cases negative. It can be recalled from Chapter IV that the effects listed in column 4 of Table V.4 were calculated as follows:

$$\text{Effect}_A \text{ (column 4, Table V.4)} = \frac{A_{\text{contrast}}}{8 \cdot 2^{(11-4-1)}} = \overline{A_{\text{HIGH}}} - \overline{A_{\text{LOW}}} .$$

Thus the effect shown in column 4 of Table V.4 reflects the mean of all observations where the factor was at its high level minus the mean of all observations where the factor was at its low level. An identical argument holds for both main effects and interaction effects. Thus a positive effect shown in column 4 of Table V.4 indicates that the

mean at the high level was greater than the mean at the low level, and a negative effect in column 4 of Table V.4 indicates that the mean at the low level was greater than the mean at the high level. In the context of this analysis a positive effect indicates that a greater degree of threat is associated with the high level of the factor or interaction while a negative effect indicates that a greater degree of threat is associated with the low level of the factor or interaction.

The interpretation of main effects is very straightforward and in most cases the subsequent discussion of these will seem elementary. Interpretation of interactions, particularly 3-factor interactions, is quite difficult and the discussion will in general be quite involved. The ANOVA for simple main effects and the ANOVA for simple simple main effects and simple interaction effects, as discussed in Chapter IV, were utilized in interpreting the significance of the 2-factor interactions EK, FJ, and KL, and the 3-factor interactions ADK, AEK, and FGL. The individual cell means associated with each interaction were also utilized. The extent of the discussion thus allocated to each factor or interaction is in no way intended as a reflection of its relative importance.

It should also be noted from column 2 of Table V.4 that EK is aliased with BDH, FJ with BDG, and ADK with BCJ. The discussion in this chapter is based on the assumption that the 2-factor interactions EK and FJ are more important

than their 3-factor aliases BDH and BDG. An interpretation of the ADK interaction is given in lieu of the BCJ interaction since ADK offered the simplest explanation. The reader is cautioned that either ADK or BCJ or both might be significant since the alias pattern of the experimental plan allows no clear interpretation in this case.

C. INTERPRETATION OF SIGNIFICANT MAIN EFFECTS

1. Factor J

J -- turret orientation of enemy target relative to the friendly tank

J_{LOW} -- turret is pointed away from friendly tank

J_{HIGH} -- turret is pointed at friendly tank

The turret orientation of the enemy target was found to be unquestionably the single most important factor impacting on the tank commander's assessment of the immediate threat posed by an enemy target. The tank commander's assessment of threat increases dramatically when the turret of the enemy target is pointed at him. Similarly, he feels much less threatened when the turret of the enemy target is pointed away from him.

2. Factor L

L -- Range between observer and target

L_{LOW} -- Range is within 2000 meters

L_{HIGH} -- Range exceeds 2000 meters

The range between target and observer was the second most critical factor impacting on the tank commander's

assessment of the immediate threat posed by a target on the battlefield. The tank commander feels much more threatened by targets that are within 2000 meters of his position than those that exceed 2000 meters.

3. Factor K

K -- Range between observer and target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

The tank commander feels much more threatened by a target at the 1050 meter range than one at the 1700 meter range. It should be noted here that the impact of this range factor is much less severe than the impact of range factor L described above. This undoubtedly reflects the fact that the tank commander, although associating a much greater threat with targets at 1050 meters, also feels highly threatened by targets at 1700 meters as well. It appears that in the case of factor L described above that very little immediate threat is assessed to targets whose range exceeds 2000 meters.

4. Factor F

F -- enemy target's position relative to friendly tank's sector of responsibility

F_{LOW} -- enemy target is not in the sector

F_{HIGH} -- enemy target is in the sector

The tank commander feels much more threatened when confronted by a target within his sector than by one outside of his sector.

5. Factor H

H -- enemy target type

H_{LOW} -- BMP/BRDM with sagger

H_{HIGH} -- Tank T72

The tank commander in general feels more threatened by an enemy tank than by a BMP or BRDM with sagger.

6. Factor G

G -- intelligence on previous firing activity of the target

G_{LOW} -- target has not been detected firing in the previous 60 seconds

G_{HIGH} -- target has been detected firing in the previous 60 seconds

The tank commander feels relatively more threatened by a target that is known to have fired in the last 60 seconds than by one that has not been detected firing in the last 60 seconds.

D. INTERPRETATION OF SIGNIFICANT 2-FACTOR INTERACTIONS

1. EK Interaction (Table V.5.1)

E -- cover/concealment of the enemy target

E_{LOW} -- fully exposed

E_{HIGH} -- not fully exposed

K -- range to enemy target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

The tank commander feels significantly more threatened when confronted by a target that is fully exposed at a range

of 1050 meters than by one that is not fully exposed at a range of 1050 meters. A much greater threat is associated with fully exposed targets at 1050 meters than similar targets at 1700 meters. The degree of exposure of the enemy target has relatively little impact at ranges of 1700 meters.

2. FJ Interaction (Table V.5.2)

F -- enemy target's position relative to the friendly tanks sector of responsibility

F_{LOW} -- enemy target is not in the sector

F_{HIGH} -- enemy target is in the sector

J -- turret orientation of enemy target relative to the friendly tank

J_{LOW} -- turret is pointed away from the friendly tank

J_{HIGH} -- turret is pointed at the friendly tank

The tank commander feels much more threatened when confronted by a target that is within his sector and whose turret is pointed at him than by a similar target outside his sector. Whether the target is in or out of the tank commander's sector of responsibility has relatively little impact if the turret of the target is pointed away from the tank commander. Turret orientation of the enemy target relative to the friendly tank impacts greatly on the tank commander's assessment of threat regardless of the target's position relative to the tank commander's sector of responsibility. However, turret orientation of the enemy target impacts much more severely if the target is also in the sector

of responsibility. Unquestionably, the tank commander associates the greatest threat with a target that is within his sector of responsibility and whose turret is pointed at him.

3. KL Interaction (Table V.5.3)

Recall from Chapter III that K and L are pseudo factors for range and that four levels of range were in fact investigated in the study. The contrast used to estimate the KL interaction thus represents one of the three degrees of freedom attributable to the four levels of range. In this respect this interaction is different than the 2-factor interactions FJ and EK previously discussed.

The cell means shown in Table V.5.3 reflect the mean of observations at four distinct ranges.

		L (LOW)	L (HIGH)
K	(LOW)	1050 m	2350 m
	(HIGH)	1700 m	3000 m

It can easily be seen that there is a direct correlation between the threat assessed by the tank commander and the range between target and observer. Specifically, the tank commander feels very threatened when confronted by a target at a range of 1050 meters, somewhat less threatened by a target at a range of 1700 meters, much less threatened by

a target at a range of 2350 meters, and very much less threatened by a target at a range of 3000 meters.

E. INTERPRETATION OF SIGNIFICANT 3-FACTOR INTERACTIONS

1. ADK Interaction (Table V.6.1)

A -- on-board rounds remaining

A_{LOW} -- above critical level

A_{HIGH} -- at or below critical level

D -- speed of enemy target

D_{LOW} -- not fast

D_{HIGH} -- fast

K -- range to enemy target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

Differences in ranges of 1050 meters and 1700 meters greatly influence the tank commander's assessment of the immediate threat posed by an enemy target, however the relative impact of these range differences is highly dependent upon the speed of the enemy target and the on-board ammunition available to the friendly tank. Given that on-board ammunition is above the critical level and the speed of the target is fast, the tank commander associates a much greater threat if the target is at a range of 1050 meters than one at a range of 1700 meters. A similar argument holds when the on-board ammunition is below the critical level and the speed of the target is not fast. In the two situations described above, the difference in range impacts severely

on the overall threat assessed. The impact of the range differential is relatively small when on-board ammunition is above the critical level and the speed of the enemy target is slow. Similarly, the impact of the range differential is relatively small when the on-board ammunition is below the critical level and the speed of the target is fast.

2. AEK Interaction (Table V.6.2)

A -- on-board rounds remaining

A_{LOW} -- above critical level

A_{HIGH} -- at or below critical level

E -- cover/concealment of the enemy target

E_{LOW} -- fully exposed

E_{HIGH} -- not fully exposed

K -- range to enemy target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

The relative threat which a tank commander assesses to targets at ranges of 1050 meters and 1700 meters is highly dependent upon his available ammunition and the degree of cover or concealment afforded his target. Given that the tank commander's on-board ammunition is above the critical level and that he is confronted by a fully exposed target, the tank commander assesses a much greater threat if the target is at the 1050 meter range rather than the 1700 meter range. A similar situation exists when the tank commander's

on-board rounds remaining is below the critical level and his target is not fully exposed. Again, in this situation a much greater threat is assessed if the range to target is 1050 meters rather than 1700 meters.

It should be noted that the impact of the range differential becomes insignificant in those situations where the tank commander's on-board ammunition is above the critical level and his target is not fully exposed, or when his on-board ammunition is below the critical level and his target is fully exposed. Given either of these situations, the threat assessed to the target at a range of 1050 meters differs very little from the threat assessed a similar target at a range of 1700 meters.

3. FGL Interaction (Table V.6.3)

F -- enemy target's position relative to friendly tank's sector of responsibility

F_{LOW} -- enemy target is not in the sector

F_{HIGH} -- enemy target is in the sector

G -- intelligence on previous firing activity of the enemy target

G_{LOW} -- target has not been detected firing in the last 60 seconds

G_{HIGH} -- target has been detected firing in the last 60 seconds

L -- range to target

L_{LOW} -- range is less than 2000 meters

L_{HIGH} -- range exceeds 2000 meters

It is quite apparent from observing the cell means shown in Table V.6.3 that in general a much greater threat

is assessed targets whose range is less than 2000 meters than those whose range exceeds 2000 meters. However, the relative impact of range as described here is very dependent upon whether or not the target is in the tank commander's sector of responsibility and whether or not the target has been detected firing in the last 60 seconds.

Given that an enemy target is in the sector of responsibility and has been detected firing in the last 60 seconds, the threat assessed this target is very much greater if its range is within 2000 meters. A similar situation exists when the enemy target is not in the tank commander's sector of responsibility and has not been detected firing in the last 60 seconds. Given this situation the tank commander again feels much more threatened if the target is within 2000 meters than if its range exceeds 2000 meters. Range impacts much less severely in situations where the enemy target is in the sector of responsibility but has not been detected firing in the last 60 seconds, or where the enemy target is outside the sector of responsibility and has been detected firing in the last 60 seconds.

Table V.5.1

```
                    ANOVA FOR SIMPLE MAIN EFFECTS
------------------------------------------------------------
 SOURCE               SS      DF   EFFECT        F     P(X.GT.F)
------------------------------------------------------------

E                   0.091    1   -0.019      2.395    0.122

E AT K(0)           0.253    1   -0.044      6.669    0.010   **

E AT K(1)           0.006    1    0.007      0.155    0.694

K                   1.001    1   -0.063     26.414    0.000   **

K AT E(0)           0.995    1   -0.088     26.239    0.000   **

K AT E(1)           0.175    1   -0.037      4.605    0.032

EK                  0.168    1    0.026      4.430    0.036   **
------------------------------------------------------------
**  INDICATES THAT P(X.GT.F) IS LESS THAN .0500 FOR MAIN
AND INTERACTION EFFECTS, AND LESS THAN .0250  FOR SIMPLE
MAIN EFFECTS.


   GRAND MEAN =         0.9702
                          **************
                          * CELL MEANS *
                          **************

                               K
                              ---

                      (LOW)              (HIGH)
          (LOW)        1.02367   :         0.93552
                                 :
      E          ---------------------------------
     ---                         :
         (HIGH)        0.97923   :         0.94230
                                 :
```

Table V.5.2

```
                    ANOVA FOR SIMPLE MAIN EFFECTS
------------------------------------------------------------------------
  SOURCE               SS       DF    EFFECT        F      P(X.GT.F)
------------------------------------------------------------------------

 F                    0.595     1     0.048      15.693     0.000    **

 F AT J(0)            0.042     1     0.018       1.117     0.291

 F AT J(1)            0.783     1     0.078      20.659     0.000    **

 J                    9.483     1     0.192     250.148     0.000    **

 J AT F(0)            3.378     1     0.162      89.104     0.000    **

 J AT F(1)            6.336     1     0.222     167.125     0.000    **

 FJ                   0.231     1     0.030       6.084     0.014    **
------------------------------------------------------------------------
 **  INDICATES THAT P(X.GT.F) IS LESS THAN .0500 FOR MAIN
 AND INTERACTION EFFECTS, AND LESS THAN .0250  FOR SIMPLE
 MAIN EFFECTS.


    GRAND MEAN =         0.9702

                          ***************
                          * CELL MEANS *
                          ***************

                                J
                               ---

                     (LOW)                (HIGH)
           (LOW)      0.86485    :         1.02730
                                 :
     F          -----------------------------------
    ---                          :
          (HIGH)      0.88304    :         1.10552
                                 :
```

Table V.5.3

```
                   ANOVA FOR SIMPLE MAIN EFFECTS
------------------------------------------------------------------
 SOURCE              SS      DF   EFFECT        F     P(X.GT.F)
------------------------------------------------------------------

K                  1.001    1   -0.063    26.414    0.000   **

K AT L(0)          0.122    1   -0.031     3.216    0.073

K AT L(1)          1.136    1   -0.094    29.977    0.000   **

L                  4.594    1   -0.134   121.172    0.000   **

L AT K(0)          1.339    1   -0.102    35.317    0.000   **

L AT K(1)          3.512    1   -0.166    92.633    0.000   **

KL                 0.257    1   -0.032     6.777    0.009   **

------------------------------------------------------------------
**  INDICATES THAT P(X.GT.F) IS LESS THAN .0500 FOR MAIN
AND INTERACTION EFFECTS, AND LESS THAN .0250  FOR SIMPLE
MAIN EFFECTS.


   GRAND MEAN =         0.9702
                            ***************
                            * CELL MEANS *
                            ***************

                                  L
                                 ---

                       (LOW)              (HIGH)
          (LOW)         1.05259   :         0.95031
                                  :
       K          ------------------------------------
      ---                         :
         (HIGH)         1.02172   :         0.85609
                                  :
```

Table V.6.1

```
 ANOVA FOR SIMPLE SIMPLE MAIN & SIMPLE INTERACTION EFFECTS
-----------------------------------------------------------------
  SOURCE               SS      DF     EFFECT        F     P(X.GT.F)
-----------------------------------------------------------------

  A                    0.024   1     -0.010      0.634   0.4261
  A   AT  DK(00)       0.039   1      0.025      1.026   0.3115
  A   AT  DK(01)       0.057   1     -0.030      1.494   0.2220
  A   AT  DK(10)       0.225   1     -0.059      5.945   0.0150
  A   AT  DK(11)       0.042   1      0.026      1.113   0.2917

  D                    0.008   1     -0.006      0.209   0.6478
  D   AT  AK(00)       0.091   1      0.038      2.400   0.1217
  D   AT  AK(01)       0.076   1     -0.035      2.015   0.1561
  D   AT  AK(10)       0.137   1     -0.046      3.616   0.0576
  D   AT  AK(11)       0.028   1      0.021      0.735   0.3913

  K                    1.001   1     -0.063     26.414   0.0000    **
  K   AT  AD(00)       0.074   1     -0.034      1.960   0.1619
  K   AT  AD(01)       0.724   1     -0.106     19.087   0.0000    **
  K   AT  AD(10)       0.501   1     -0.088     13.213   0.0003    **
  K   AT  AD(11)       0.029   1     -0.021      0.767   0.3816

  AD                   0.013   1     -0.007      0.344   0.5577
  AD  AT  K  ( 0)      0.226   1     -0.042      5.954   0.0149    **
  AD  AT  K  ( 1)      0.098   1      0.028      2.593   0.1077

  AK                   0.015   1      0.008      0.396   0.5295
  AK  AT  D  ( 0)      0.095   1     -0.027      2.498   0.1144
  AK  AT  D  ( 1)      0.231   1      0.043      6.102   0.0137    **

  DK                   0.000   1     -0.001      0.011   0.9174
  DK  AT  A  ( 0)      0.167   1     -0.036      4.407   0.0361
  DK  AT  A  ( 1)      0.144   1      0.034      3.807   0.0514

  ADK                  0.311   1      0.035      8.204   0.0043    **
-----------------------------------------------------------------
 **  INDICATES THAT  P(X.GT.F) IS LESS THAN  .0500  FOR MAIN
 EFFECTS, IS LESS THAN .0250 FOR SIMPLE INTERACTION EFFECTS,
 AND IS LESS THAN .0125 FOR SIMPLE SIMPLE MAIN EFFECTS.


  GRAND MEAN =          0.9702

                              **************
                              * CELL MEANS *
                              **************

                                    K
                                   ---
                   (LOW)                           (HIGH)

                     D                               D
                    ---                             ---
             (LOW)         (HIGH)          (LOW)          (HIGH)

  (LOW)      0.9913  :     1.0290          0.9572  :      0.9226
                     :                             :
 A          ---------------------------    -------------------------
---
  (HIGH)     1.0159  :     0.9696          0.9274  :      0.9483
                     :                             :
```

Table V.6.2

```
 ANOVA FOR SIMPLE SIMPLE MAIN & SIMPLE INTERACTION EFFECTS
----------------------------------------------------------------
   SOURCE                SS     DF     EFFECT        F     P(X.GT.F)
----------------------------------------------------------------

   A                   0.024    1     -0.010      0.634    0.4261
   A   AT  EK(00)      0.324    1     -0.071      8.546    0.0036    **
   A   AT  EK(01)      0.037    1      0.024      0.981    0.3224
   A   AT  EK(10)      0.085    1      0.036      2.244    0.1346
   A   AT  EK(11)      0.051    1     -0.028      1.340    0.2474

   E                   0.091    1     -0.019      2.395    0.1221
   E   AT  AK(00)      0.618    1     -0.098     16.294    0.0001    **
   E   AT  AK(01)      0.069    1      0.033      1.829    0.1766
   E   AT  AK(10)      0.006    1      0.009      0.148    0.7008
   E   AT  AK(11)      0.024    1     -0.019      0.632    0.4267

   K                   1.001    1     -0.063     26.414    0.0000    **
   K   AT  AE(00)      1.180    1     -0.136     31.124    0.0000    **
   K   AT  AE(01)      0.001    1     -0.005      0.036    0.8498
   K   AT  AE(10)      0.105    1     -0.041      2.773    0.0962
   K   AT  AE(11)      0.307    1     -0.069      8.094    0.0045    **

   AE                  0.049    1      0.014      1.292    0.2560
   AE  AT  K  ( 0)     0.370    1      0.054      9.773    0.0018    **
   AE  AT  K  ( 1)     0.087    1     -0.026      2.305    0.1292

   AK                  0.015    1      0.008      0.396    0.5295
   AK  AT  E  ( 0)     0.290    1      0.048      7.658    0.0058    **
   AK  AT  E  ( 1)     0.134    1     -0.032      3.525    0.0608

   EK                  0.168    1      0.026      4.430    0.0356    **
   EK  AT  A  ( 0)     0.550    1      0.066     14.521    0.0001    **
   EK  AT  A  ( 1)     0.026    1     -0.014      0.696    0.4044

   AEK                 0.409    1     -0.040     10.787    0.0011    **
----------------------------------------------------------------
 **  INDICATES THAT  P(X.GT.F) IS LESS THAN  .0500  FOR MAIN
 EFFECTS, IS LESS THAN .0250 FOR SIMPLE INTERACTION EFFECTS,
 AND IS LESS THAN .0125 FOR SIMPLE SIMPLE MAIN EFFECTS.


   GRAND MEAN =         0.9702

                                ***************
                                * CELL MEANS  *
                                ***************

                                       K
                                      ---
                   (LOW)                          (HIGH)

                     E                              E
                    ---                            ---
              (LOW)  :       (HIGH)         (LOW)   :       (HIGH)
                     :                              :
   (LOW)     1.0592  :       0.9610         0.9235  :       0.9564
                     :                              :
 A         --------------------------    --------------------------
---                  :                              :
   (HIGH)    0.9881  :       0.9975         0.9476  :       0.9282
                     :                              :
```

Table V.6.3

```
 ANOVA FOR SIMPLE SIMPLE MAIN & SIMPLE INTERACTION EFFECTS
-----------------------------------------------------------------
  SOURCE                 SS     DF    EFFECT       F     P(X.GT.F)
-----------------------------------------------------------------

  F                    0.595    1      0.048    15.693   0.0001   **
  F   AT GL(00)        0.024    1      0.019     0.636   0.4256
  F   AT GL(01)        0.551    1      0.093    14.530   0.0001   **
  F   AT GL(10)        0.689    1      0.104    18.167   0.0000   **
  F   AT GL(11)        0.034    1     -0.023     0.899   0.3433

  G                    0.247    1      0.031     6.514   0.0109   **
  G   AT FL(00)        0.001    1      0.004     0.028   0.8664
  G   AT FL(01)        0.348    1      0.074     9.190   0.0025   **
  G   AT FL(10)        0.500    1      0.088    13.202   0.0003   **
  G   AT FL(11)        0.113    1     -0.042     2.989   0.0842

  L                    4.594    1     -0.134   121.172   0.0000   **
  L   AT FG(00)        1.546    1     -0.155    40.787   0.0000   **
  L   AT FG(01)        0.471    1     -0.086    12.414   0.0004   **
  L   AT FG(10)        0.431    1     -0.082    11.370   0.0008   **
  L   AT FG(11)        2.892    1     -0.213    76.284   0.0000   **

  FG                   0.016    1     -0.008     0.419   0.5175
  FG  AT L  ( 0)       0.228    1      0.042     6.003   0.0145   **
  FG  AT L  ( 1)       0.429    1     -0.058    11.329   0.0008   **

  FL                   0.046    1     -0.013     1.206   0.2725
  FL  AT G  ( 0)       0.172    1      0.037     4.544   0.0333
  FL  AT G  ( 1)       0.515    1     -0.063    13.575   0.0002   **

  GL                   0.059    1     -0.015     1.561   0.2119
  GL  AT F  ( 0)       0.155    1      0.035     4.099   0.0432
  GL  AT F  ( 1)       0.545    1     -0.065    14.376   0.0002   **

  FGL                  0.641    1     -0.050    16.913   0.0000   **
-----------------------------------------------------------------
**  INDICATES THAT  P(X.GT.F) IS LESS THAN  .0500  FOR MAIN
EFFECTS, IS LESS THAN .0250 FOR SIMPLE INTERACTION EFFECTS,
AND IS LESS THAN .0125 FOR SIMPLE SIMPLE MAIN EFFECTS.


  GRAND MEAN =          0.9702

                              **************
                              * CELL MEANS *
                              **************

                                    L
                                   ---
                    (LOW)                         (HIGH)

                      G                             G
                     ---                           ---
             (LOW)         (HIGH)           (LOW)         (HIGH)

   (LOW)     1.0043   :    1.0084           0.8489   :    0.9227
                      :                              :
 F          ---------------------------   ---------------------------
---
   (HIGH)    1.0237   :    1.1122           0.9417   :    0.8996
                      :                              :
```

VI. ANALYSIS OF FACTORS RELEVANT TO THE FIRE/NO-FIRE DECISION INDEX

A. GENERAL COMMENTS CONCERNING THE ANALYSIS

The purpose of the analysis discussed in this chapter was to provide insight into the relative importance of each of the 11 factors investigated with respect to the tank commander's decision to engage or not engage a specific target. Recall from Chapter III that the data base used in this analysis, as shown in Table III.3, consists of 1024 observations of 'yes' and 'no' responses reflecting the tank commander's decision to engage (yes) or not engage (no) in each of the situations described by the treatment combinations of the experimental plan. The data was coded as 1 for 'yes' and 0 for 'no'. The primary statistical tool used in the analysis was the Factorial Chi-Square [3].

B. THE FACTORIAL CHI-SQUARE

The Factorial Chi-Square, although in general not as precise as the ANOVA, is very simple and very appropriate for attribute data of the type shown in Table III.3. The hypothesis tested using this technique is identical to that tested in the treatment ANOVA of Table V.4, specifically the following:

H_0: Effect of A is negligible.

H_1: Effect of A is significant.

It can be shown that in a 2^n factorial the following statistic is approximately distributed according to the chi-square distribution with one degree of freedom [3]:

$$X_{(1)} = \frac{N}{(S)(F)} \times \text{contrast}^2$$

where:

N is the total number of observations in the experiment

S is the total number of occurrences, and

F is the total number of non-occurrences.

If we consider each observation in Table III.3 as a Bernoulli trial with two possible outcomes being 'yes' or 'no', then the sum of all observations will be distributed Binomial (NP,NPQ), where P equals the probability of a 'yes' and Q equals the probability of a 'no'. Then the statistic $\frac{X - NP}{\sqrt{NPQ}}$ is approximately Normal(0,1). Under the null hypothesis, the E[contrast] equals 0 and thus the statistic $\frac{\text{contrast}}{\sqrt{NPQ}}$ is approximately Normal(0,1). Accordingly, the statistic $\frac{\text{contrast}^2}{NPQ}$ is approximately distributed as chi-square with one degree of freedom. Since $P = S/N$ and $Q = F/N$, the statistic as defined above, specifically $\frac{N}{(S)(F)} \times \text{contrast}^2$, will under the null hypothesis be distributed chi-square with one degree of freedom and can be used for testing the hypothesis stated above. The only restriction that applies

to the use of this technique in the $2^{(n-p)}$ fractional factorial is in the interpretation of the results. Specifically, the same arguments concerning the aliases of each effect, as previously mentioned in the use of the ANOVA, also apply to the use of the factorial chi-square.

The results of this analysis are presented in Table VI. Columns 1 and 2 of Table VI correspond directly to columns 1 and 2 of the treatment ANOVA shown in Table V.4. Column 3 reflects the single degree of freedom attributable to the single unique contrast used in estimating the effect listed in column 1. Column 4 reflects the contrast of the source shown in column 1. Column 5 reflects the calculated chi-square statistic as described above. Thus in our case,

$$\text{Chi-square statistic} \quad = \quad \frac{8 \cdot 2^{(11-4)} . \text{contrast}^2}{(\#\text{YES})(\#\text{NO})} \; .$$

The decision to reject or not to reject the null hypothesis was based on comparing the right-hand tail probability associated with the calculated chi-square statistic, column 6 of Table VI, with the significance level selected for the analysis, specifically .05.

The remainder of this chapter is devoted to the identification and interpretation of those factors and interactions that were found to significantly impact on the tank commander's decision to engage or not engage a specific target. It should be noted from Table VI that the contrasts reflected in column 4 are in some cases positive and in other

Table VI

FACTORIAL CHI-SQUARE ANALYSIS

SOURCE	2/3 FI ALIAS	DF	CONTRAST	CHI SQUARE STATISTIC	PROB (X.GT.CS)	
A	NONE	1	-51.0000	10.3164	0.0013	*
B	NONE	1	7.0000	0.1943	0.6593	
C	NONE	1	-37.0000	5.4299	0.0198	*
D	NONE	1	-17.0000	1.1463	0.2843	
E	NONE	1	-45.0000	8.0318	0.0046	*
F	NONE	1	19.0000	1.4318	0.2315	
G	NONE	1	33.0000	4.3193	0.0377	*
H	NONE	1	35.0000	4.8587	0.0275	*
J	NONE	1	127.0000	63.9725	0.0000	*
K	NONE	1	-59.0000	13.8067	0.0002	*
L	NONE	1	-223.0000	197.2402	0.0	*
AB	NONE	1	1.0000	0.0040	0.9498	
AC	FGK EHJ	1	-3.0000	0.0357	0.8501	
AD	EGL	1	-23.0000	2.0982	0.1475	
AE	DGL CHJ	1	-3.0000	0.0357	0.8501	
AF	CGK	1	9.0000	0.3213	0.5708	
AG	DEL CFK	1	-17.0000	1.1463	0.2843	
AH	CEJ	1	21.0000	1.7491	0.1860	
AJ	CEH	1	41.0000	6.6674	0.0098	*
AK	CFG	1	15.0000	0.8924	0.3448	
AL	DEG	1	-1.0000	0.0040	0.9498	
BC	FHL	1	-13.0000	0.6703	0.4129	
BD	FGJ EHK	1	3.0000	0.0357	0.8501	
BE	DHK	1	-1.0000	0.0040	0.9498	
BF	DGJ CHL	1	-17.0000	1.1463	0.2843	

* INDICATES THAT P(X.GT.CS) IS LESS THAN .05

Table VI (continued)

SOURCE	2/3 FI ALIAS	DF	CONTRAST	CHI SQUARE STATISTIC	PROB (X.GT.CS)
BG	DFJ	1	5.0000	0.0992	0.7528
BH	CFL DEK	1	7.0000	0.1943	0.6593
BJ	DFG	1	-5.0000	0.0992	0.7528
BK	DEH	1	-7.0000	0.1943	0.6593
BL	CFH	1	9.0000	0.3213	0.5708
CD	NONE	1	11.0000	0.4799	0.4885
CE	AHJ	1	3.0000	0.0357	0.8501
CF	AGK BHL	1	11.0000	0.4799	0.4885
CG	AFK	1	17.0000	1.1463	0.2843
CH	BFL AEJ	1	7.0000	0.1943	0.6593
CJ	AEH	1	27.0000	2.8914	0.0891
CK	AFG	1	-27.0000	2.8914	0.0891
CL	BFH	1	9.0000	0.3213	0.5708
DE	AGL BHK	1	11.0000	0.4799	0.4885
DF	BGJ	1	3.0000	0.0357	0.8501
DG	AEL BFJ	1	-23.0000	2.0982	0.1475
DH	BEK	1	-5.0000	0.0992	0.7528
DK	BEH	1	17.0000	1.1463	0.2843
DJ	BFG	1	3.0000	0.0357	0.8501
DL	AEG	1	13.0000	0.6703	0.4129
EF	NONE	1	-17.0000	1.1463	0.2843
EG	ADL	1	1.0000	0.0040	0.9498
EH	BDK ACJ	1	-9.0000	0.3213	0.5708
EJ	ACH	1	3.0000	0.0357	0.8501
EK	BDH	1	21.0000	1.7491	0.1860
EL	ADG	1	-19.0000	1.4318	0.2315

* INDICATES THAT P(X.GT.CS) IS LESS THAN .05

Table VI (continued)

SOURCE	2/3 FI ALIAS	DF	CONTRAST	CHI SQUARE STATISTIC	PROB (X.GT.CS)
FG	ACK BDJ	1	-11.0000	0.4799	0.4885
FH	BCL	1	-9.0000	0.3213	0.5708
FJ	BDG	1	-1.0000	0.0040	0.9498
FK	ACG	1	13.0000	0.6703	0.4129
FL	BCH	1	-11.0000	0.4799	0.4885
GH	NONE	1	-19.0000	1.4318	0.2315
GJ	BDF	1	-11.0000	0.4799	0.4885
GK	ACF	1	-21.0000	1.7491	0.1860
GL	ADE	1	-1.0000	0.0040	0.9498
HJ	ACE	1	-9.0000	0.3213	0.5708
HK	BDE	1	-3.0000	0.0357	0.8501
HL	BCF	1	-15.0000	0.8924	0.3448
JK	NONE	1	-7.0000	0.1943	0.6593
JL	NONE	1	-3.0000	0.0357	0.8501
KL	NONE	1	-37.0000	5.4299	0.0198 *
ABC	DJK	1	-7.0000	0.1943	0.6593
ABD	CJK	1	9.0000	0.3213	0.5708
ABE	FJL	1	5.0000	0.0992	0.7528
ABF	EJL	1	1.0000	0.0040	0.9498
ABG	HKL	1	-9.0000	0.3213	0.5708
ABH	GKL	1	5.0000	0.0992	0.7528
ABJ	CDK EFL	1	-7.0000	0.1943	0.6593
ABL	EFJ GHK	1	11.0000	0.4799	0.4885
ACD	BJK	1	-7.0000	0.1943	0.6593
ACL	NONE	1	19.0000	1.4318	0.2315
ADF	NONE	1	5.0000	0.0992	0.7528
ADH	NONE	1	-23.0000	2.0982	0.1475
ADJ	BCK	1	25.0000	2.4789	0.1154

* INDICATES THAT P(X.GT.CS) IS LESS THAN .05

Table VI (continued)

SOURCE	2/3 FI ALIAS	DF	CONTRAST	CHI SQUARE STATISTIC	PROB (X.GT.CS)
ADK	BCJ	1	-9.0000	0.3213	0.5708
AEF	BJL	1	17.0000	1.1463	0.2843
AEK	NONE	1	-21.0000	1.7491	0.1860
AFH	NONE	1	1.0000	0.0040	0.9498
AFJ	BEL	1	1.0000	0.0040	0.9498
AGH	BKL	1	-17.0000	1.1463	0.2843
AHK	BGL	1	-5.0000	0.0992	0.7528
AHL	BGK	1	19.0000	1.4313	0.2315
AJK	BCD	1	-9.0000	0.3213	0.5708
AJL	BEF	1	-17.0000	1.1463	0.2843
AKL	BGH	1	5.0000	0.0992	0.7528
BCE	NONE	1	7.0000	0.1943	0.6593
BCG	NONE	1	21.0000	1.7491	0.1860
BEG	NONE	1	17.0000	1.1463	0.2843
BFK	NONE	1	-3.0000	0.0357	0.8501
BHJ	NONE	1	15.0000	0.8924	0.3448
CDE	FKL	1	3.0000	0.0357	0.8501
CDF	EKL	1	19.0000	1.4313	0.2315
CDG	HJL	1	9.0000	0.3213	0.5708
CDH	GJL	1	23.0000	2.0982	0.1475
CDL	EFK GHJ	1	13.0000	0.6703	0.4129
CEF	DKL	1	11.0000	0.4799	0.4885
CEG	NONE	1	-11.0000	0.4799	0.4885
CEK	DFL	1	1.0000	0.0040	0.9498
CFJ	NONE	1	-9.0000	0.3213	0.5708
CGH	DJL	1	-11.0000	0.4799	0.4885
CGJ	DHL	1	-11.0000	0.4799	0.4885
CGL	DHJ	1	-5.0000	0.0992	0.7528
CJL	DGH	1	-3.0000	0.0357	0.8501

* INDICATES THAT P(X.GT.CS) IS LESS THAN .05

Table VI (continued)

SOURCE	2/3 FI ALIAS	DF	CONTRAST	CHI SQUARE STATISTIC	PROB (X.GT.CS)
CKL	DEF	1	15.0000	0.8924	0.3448
DEJ	NONE	1	23.0000	2.0982	0.1475
DFH	NONE	1	7.0000	0.1943	0.6593
DGK	NONE	1	7.0000	0.1943	0.6593
EFG	HJK	1	-11.0000	0.4799	0.4885
EFH	GJK	1	3.0000	0.0357	0.8501
EGH	FJK	1	-11.0000	0.4799	0.4885
EGJ	FHK	1	5.0000	0.0992	0.7528
EHL	NONE	1	5.0000	0.0992	0.7528
EJK	FGH	1	-15.0000	0.8924	0.3448
FGL	NONE	1	-13.0000	0.6703	0.4129
JKL	NONE	1	19.0000	1.4318	0.2315

* INDICATES THAT P(X.GT.CS) IS LESS THAN .05

cases negative. Recall from Chapter II that this contrast represents the difference between the sum of all observations where the source listed in column 1 was at its high level and the sum of all observations where the source listed in column 1 was at its low level. Thus, in the context of this analysis, a positive contrast in column 4 of Table VI indicates that the tank commander places greater emphasis on engaging targets where the corresponding source shown in column 1 is at the high level. Similarly, a negative contrast in column 4 of Table VI indicates that the tank commander places greater emphasis on engaging targets where the corresponding source shown in column 1 is at its low level.

C. IDENTIFICATION OF SIGNIFICANT FACTORS AND INTERACTIONS

The factorial chi-square analysis shown in Table VI reflects the investigation of 120 various treatment effects, of which 10 were identified as being significant at the .05 level; specifically, the main effects A,C,E,G,H,J,K, and L; and the 2-factor interactions AJ and KL. It should be noted from column 2 of Table VI that AJ is aliased with CEH. It is assumed that the 2-factor interaction AJ is more important than the 3-factor interaction CEH and that the contrast corresponding to AJ in Table VI was in fact due to the AJ interaction rather than the CEH interaction. All other significant effects are free of 3-factor aliases and thus provide a clear interpretation. A reordering of the

significant effects based on their relative importance, as indicated by a comparison of the magnitude of their corresponding contrasts, is as follows: L,J,K,A,E,AJ,C,KL,H, and G.

D. INTERPRETATION OF SIGNIFICANT MAIN EFFECTS

1. Factor L

L -- range to enemy target

L_{LOW} -- range is less than 2000 meters

L_{HIGH} -- range exceeds 2000 meters

This range factor was by far the most significant factor identified in the analysis. It appears that tank commanders rarely choose to engage targets at ranges exceeding 2000 meters while in the majority of cases most will choose to engage targets within 2000 meters. This undoubtedly reflects the fact that the probability of hitting a target is greatly reduced at ranges exceeding 2000 meters.

2. Factor J

J -- turret orientation of the enemy target relative to the friendly tank

J_{LOW} -- turret is pointed away from friendly tank

J_{HIGH} -- turret is pointed at friendly tank

The turret orientation of the enemy target seriously impacts on the tank commander's decision to engage or not engage the target. In general tank commanders are much more likely to engage a target whose turret is pointed at them than one whose turret is pointed away from them.

3. Factor K

K -- range between observer and target

K_{LOW} -- 1050 meters

K_{HIGH} -- 1700 meters

Tank commanders are much more likely to engage targets at ranges of 1050 meters than targets at ranges of 1700 meters. Tank commanders will in the great majority of cases choose to engage targets at ranges of 1050 meters but are much more selective in choosing to engage targets at the 1700 meter range.

4. Factor A

A -- on-board ammunition remaining

A_{LOW} -- above critical level

A_{HIGH} -- at or below critical level

On-board ammunition available impacts significantly on the tank commander's decision to engage or not engage a target. Tank commanders are much more selective in choosing to engage targets when their on-board ammunition is below the critical level.

5. Factor E

E -- cover/concealment of the enemy target

E_{LOW} -- fully exposed

E_{HIGH} -- not fully exposed

The tank commander in general is much less likely to engage a target that is afforded cover or concealment than one that is fully exposed. Thus the tank commander is

more selective in choosing to engage targets that are not fully exposed as compared to those that are fully exposed.

6. Factor C

C -- anticipated resupply

C_{LOW} -- soon

C_{HIGH} -- not soon

Anticipated resupply significantly impacts on the tank commander's decision to engage or not engage an enemy target. The tank commander is more selective in choosing to engage targets when his anticipated resupply is not soon.

7. Factor H

H -- enemy target type

H_{LOW} -- BMP/BRDM with sagger

H_{HIGH} -- Tank T72

Tank commanders will in general choose to engage a tank target more frequently than a BMP or BRDM. It is important to remember that engagement in this sense refers to the main gun and does not consider the secondary armament that is available to the tank commander.

8. Factor G

G -- intelligence on previous firing activity of the enemy target

G_{LOW} -- target has not been detected firing in the previous 60 seconds

G_{HIGH} -- target has been detected firing in the previous 60 seconds

A tank commander is more likely to engage a target if he has detected the target firing in the previous 60 seconds than if no detection of firing has been made.

E. INTERPRETATION OF SIGNIFICANT 2-FACTOR INTERACTIONS

1. AJ Interaction

A -- on-board ammunition remaining

A_{LOW} -- above critical level

A_{HIGH} -- at or below critical level

J -- turret orientation of the enemy target relative to the friendly tank

J_{LOW} -- turret is pointed away from the friendly tank

J_{HIGH} -- turret is pointed at the friendly tank

Percentage of 'YES' Responses

		J	
		(LOW)	(HIGH)
A	(LOW)	52.7%	69.5%
	(HIGH)	34.8%	67.6%

It appears that significantly more tank commanders choose to engage targets whose turret is pointed at them than targets whose turret is pointed away from them. On-board ammunition in general has little impact in situations where the tank commander is confronted by a target whose turret is pointed at him. However, on-board ammunition impacts severely when the tank commander is confronted by a target

whose turret is pointed away from him. In this situation the tank commander becomes very selective in choosing to engage such a target when his on-board ammunition is below the critical level. Many tank commanders choose not to engage such a target when their ammunition is below the critical level.

2. KL Interaction

Recall from Chapter III that K and L are pseudo factors for range and that four levels of range were in fact investigated in the study. The contrast used to estimate the KL interaction thus represents one of the three degrees of freedom attributable to the four levels of range. In this respect this interaction is different from the 2-factor interaction AJ. The four distinct ranges investigated in the study are represented by the following combinations of K and L:

		L	
		(LOW)	(HIGH)
K	(LOW)	1050 m	2350 m
	(HIGH)	1700 m	3000 m

Percentage of 'YES' Responses

		L	
		(LOW)	(HIGH)
K	(LOW)	80.0%	43.8%
	(HIGH)	75.8%	25.0%

It can easily be seen that there is a direct correlation between the decision to engage or not engage an enemy target and the range between target and observer. Tank commanders will in the great majority of cases choose to engage targets at ranges of 1050 meters and 1700 meters, and will in the great majority of cases choose not to engage targets beyond the 1700 meter range.

VII. THE TARGET SELECTION MODEL

A. GENERAL

A primary goal of this thesis was to enhance the Simulation of Tactical Alternative Responses (STAR) model by developing a realistic target selection model. Recall from Chapter I that the major problem of the target selection model used in the present version of STAR is its failure to realistically prioritize the various threat levels associated with targets within a given array. The model presented in this chapter concerns itself with this task and is a best fit regression model based on the threat index data shown in Table III.2. The model is thus a direct consequence of the threat index analysis presented in Chapter V.

B. THE MODEL

Table VII.1 depicts the model that was developed from the analysis of Chapter V. The various statistics presented in this table thus summarize the significant results of the treatment ANOVA shown in Table V.4. The entries in either table are identical with the exception of the regression coefficients in column 2 of Table VII.1. It can be verified that these equal $\frac{1}{2}$ the effect shown in column 4 of the treatment ANOVA (Table V.4). The model thus depicted is based on nine different factors and can be described as follows:

Table VII.1

STATISTICS FOR SELECTED MODEL

VARIABLE	REGRESSION COEFFICIENT	SUM OF SQUARES	DF	F STATISTIC	PROB (X.GT.F)	
MEAN	0.97018	963.836	1			
F	0.02410	0.595	1	15.694	0.0001	*
G	0.01553	0.247	1	6.514	0.0109	*
H	0.01554	0.247	1	6.521	0.0108	*
J	0.09623	9.483	1	250.152	0.0000	*
K	-0.03127	1.001	1	26.415	0.0000	*
L	-0.06698	4.594	1	121.174	0.0000	*
EK	0.01281	0.168	1	4.430	0.0356	
FJ	0.01501	0.231	1	6.084	0.0138	*
KL	-0.01584	0.257	1	6.778	0.0094	*
ADK	0.01743	0.311	1	8.204	0.0043	*
AEK	-0.01998	0.409	1	10.787	0.0011	*
FGL	-0.02502	0.641	1	16.914	0.0000	*
TOTAL REGRESSION		982.020	13			

* INDICATES SIGNIFICANCE AT .025

$$\text{ADJT (Adjusted Threat)} = .97018 + .02410X_1 + .01553X_2$$
$$+ .01554X_3 + .09623X_4 - .03127X_5 - .06698X_6$$
$$+ .01281X_5X_7 + .01501X_1X_4 - .01584X_5X_6$$
$$+ .01743X_5X_8X_9 - .01998X_5X_7X_8 - .02502X_1X_2X_6$$

where:

$$X_1 = \begin{cases} +1 & \text{if target is in sector of responsibility} \\ -1 & \text{if target is not in sector} \end{cases}$$

$$X_2 = \begin{cases} +1 & \text{if target has been detected firing in previous 60 seconds} \\ -1 & \text{if target has not been detected firing in previous 60 seconds} \end{cases}$$

$$X_3 = \begin{cases} +1 & \text{if target is an enemy tank} \\ -1 & \text{if target is a BMP or BRDM} \end{cases}$$

$$X_4 = \begin{cases} +1 & \text{if turret of target pointed at friendly tank} \\ -1 & \text{if turret pointed away from friendly tank} \end{cases}$$

$$X_5 = \begin{cases} +1 & \text{if } 1400\text{ m} < \text{RANGE} \leq 2000\text{ m} \;\underline{\text{or}}\; \text{RANGE} > 2600\text{ m} \\ -1 & \text{if RANGE} \leq 1400\text{ m} \;\underline{\text{or}}\; 2000\text{ m} < \text{RANGE} \leq 2600\text{ m} \end{cases}$$

$$X_6 = \begin{cases} +1 & \text{if RANGE} > 2000 \text{ m} \\ -1 & \text{if RANGE} \leq 2000 \text{ m} \end{cases}$$

$$X_7 = \begin{cases} +1 & \text{if target is not fully exposed} \\ -1 & \text{if target is fully exposed} \end{cases}$$

$$X_8 = \begin{cases} +1 & \text{if on-board ammunition is at or below critical level} \\ -1 & \text{if on-board ammunition is above critical level} \end{cases}$$

$$X_9 = \begin{cases} +1 & \text{if speed of target is fast} \\ -1 & \text{if speed of target is not fast} \end{cases}$$

Various statistics based on the model are shown in the general ANOVA, Table VII.2. Recall from Chapter V that the sum of squares due to regression accounted for 86 percent of the total treatment sum of squares. The regression (terms) entry in the ANOVA is significant at the .0001 level while the lack of fit is very insignificant. This indicates that the model is an adequate representation of the data. It should be noted that only 31.8 percent of the total variability could possibly be explained by regression with a model of 120 terms because of the large variability over the eight replications of each treatment. The seclected model accounts for 27.3 percent of the total variability

Table VII.2

```
                 GENERAL ANOVA FOR SELECTED MODEL
------------------------------------------------------------
                    SUM OF           MEAN        F        PROB
 SOURCE            SQUARES    DF   SQUARES  STATISTIC (X.GT.F)
------------------------------------------------------------

MEAN                963.836    1   963.836

REGRESSION(TERMS)    18.184   12     1.515     39.972  0.0000 **

RESIDUAL             48.346 1011

  LACK OF FIT         2.991  108     0.028      0.731  0.9796

  SOURCES(BETWEEN)   13.510   63

  ERROR(ADJUSTED)    31.844  840     0.038

------------------------------------------------------------
TOTAL              1030.366 1024
------------------------------------------------------------
*   INDICATES SIGNIFICANCE AT .05
**  INDICATES SIGNIFICANCE AT .01



PERCENT VARIABILITY THAT CAN BE
EXPLAINED BY REGRESSION:  31.8284 %

PERCENT VARIABILITY EXPLAINED BY SELECTED MODEL:   27.3322 %

SAMPLE MULTIPLE CORRELATION COEFFICIENT:      0.5228

STANDARD DEVIATION OF RESIDUALS:      0.0629

MEAN RESIDUAL MAGNITUDE:      0.0503

MAXIMUM DEVIATION BETWEEN PREDICTED
AND MEAN OF OBSERVED VALUES:      0.1466

PERCENTAGE OF OBSERVED VALUES FALLING WITHIN
1(ONE) STANDARD DEVIATION OF REGRESSION LINE:      71.09 %

PERCENTAGE OF OBSERVED VALUES FALLING WITHIN
2(TWO) STANDARD DEVIATIONS OF REGRESSION LINE:      96.09 %

NUMBER OF RESIDUALS WHOSE MAGNITUDE IS GREATER
THAN 2(TWO) STANDARD DEVIATIONS:      5
```

(27.3/31.8 = 85.8% of possible) using only twelve terms, thus leading to a considerably simpler interpretation than one with 120.

The residuals of differences between the mean of observations for each treatment and the value predicted by the model are given in Table VII.3. The statistics based on these residuals, shown in Table VII.2, indicate that the predicted values do in general closely agree with the observed average values. This is indicated by the very small mean residual magnitude of .0503 and a similarly small standard deviation of .0629. A high positive correlation was realized in comparing the priority ranking based on average observed values and the priority ranking based on predicted values. Differences in the two rankings were srutinized by experienced Armor officers on a situation by situation basis. The priority schemes generated by the model were in all such cases deemed reasonable and intuitive.

It is the author's opinion that the model thus depicted does represent the current state of the art and is a viable alternative to the target selection models presently used in either STAR or DYNTACS. This opinion is based in part not only on the fact that the model fits the data well, but also on the fact, as previously stated in Chapter III, that the data base is credible and current. The model is simple and can be easily implemented in most existing high-resolution simulation models. Its use, particularly in the simulation of combat involving a large armor force, should impact considerably on the overall realism achieved in the simulation.

Table VII.3
Comparison of Predicted Versus Observed Values

TREATMENT	MEAN OF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL
BEFGJ	1.0162	1.1627	-0.147 *
CEFHJL	0.9304	1.0605	-0.130 *
ACDEGHK	0.8075	0.9327	-0.125
ABGH	0.8424	0.9636	-0.121
BDFHJKL	0.8481	0.9662	-0.118
ABCDEFGH	0.8998	1.0113	-0.112
ABCDFGL	0.7073	0.8135	-0.106
BCEHJKL	0.8347	0.9384	-0.104
ABCD	0.8183	0.9166	-0.098
ABCEJ	1.0306	1.1283	-0.098
AHKL	0.6206	0.7155	-0.095
ABDEFHJL	1.0059	1.1004	-0.094
ABCDEHL	0.7227	0.8097	-0.087
BDEFJK	1.0307	1.1163	-0.086
ABCEFGJL	1.0025	1.0852	-0.083
BCDHKL	0.5930	0.6755	-0.083
BDFG	0.9598	1.0407	-0.081
DEFGJL	0.9673	1.0453	-0.078
BCDEFGKL	0.6815	0.7593	-0.078
DEJ	1.0189	1.0883	-0.069
BDEGJKL	0.8866	0.9536	-0.067
ADJK	1.0363	1.0974	-0.061
AEGHJL	1.0295	1.0881	-0.059
EHL	0.7116	0.7698	-0.058
BFK	0.8077	0.8631	-0.055
BEGHK	0.9174	0.9727	-0.055
ADFGJKL	0.9366	0.9910	-0.054
ABCDEGJK	1.0168	1.0641	-0.047
BCJK	1.0132	1.0574	-0.044
CDEHJK	1.0780	1.1192	-0.041
CGJL	1.0066	1.0478	-0.041
AEFGKL	0.6785	0.7193	-0.041
ACDFK	0.8637	0.9031	-0.039
ACEFJK	1.0385	1.0764	-0.038
CDEFGHJKL	0.9750	1.0128	-0.038
(1)	0.9205	0.9566	-0.036
ABDEGHJ	1.0701	1.1055	-0.035
ACGHJK	1.0396	1.0746	-0.035
BCFH	0.9209	0.9558	-0.035
ABCGK	0.8470	0.8811	-0.034
CEFGK	0.9800	1.0098	-0.030
EFGH	0.9432	0.9713	-0.028
AGJ	1.0674	1.0949	-0.028
GHJKL	0.9282	0.9539	-0.026
ACDGKL	0.7752	0.8004	-0.025
ACDHJ	1.0891	1.1101	-0.021
ABCEGHKL	0.7625	0.7822	-0.020
ABDFJ	1.0875	1.1072	-0.020
ABEHJK	1.0602	1.0793	-0.019
ABCDGHJKL	0.9755	0.9939	-0.018
ACEGJKL	0.8957	0.9136	-0.018
ABDHK	0.9510	0.9660	-0.015
CDEF	0.8803	0.8940	-0.014
BCEFGHJK	1.2550	1.2634	-0.008
CDGH	0.9956	1.0035	-0.008
ADEFGHJK	1.2163	1.2234	-0.007
CDEGL	0.8477	0.8546	-0.007
CHK	0.9239	0.9261	-0.002

* INDICATES RESIDUAL MAGNITUDE EXCEEDS
2 (TWO) STANDARD DEVIATIONS

Table VII.3 (continued)

TREATMENT	MEAN OF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL
ABEFGHJKL	0.9714	0.9729	-0.001
BCDEGHJL	1.0492	1.0482	0.001
BCFGJKL	0.9532	0.9510	0.002
ABDGJL	1.0119	1.0078	0.004
AFGHK	0.9848	0.9804	0.004
ACEFGHL	0.8997	0.8938	0.006
FGL	0.8603	0.8535	0.007
CFJ	1.1569	1.1472	0.010
AFJL	1.1007	1.0899	0.011
ACFG	1.0116	1.0007	0.011
ADGHL	0.8876	0.8765	0.011
ADEFL	0.8596	0.8469	0.013
FHJK	1.1295	1.1167	0.013
ABFHL	0.9113	0.8985	0.013
ABCDEFJKL	1.0094	0.9956	0.014
DEFHK	0.9396	0.9249	0.015
DFKL	0.7277	0.7127	0.015
ABEF	0.9534	0.9340	0.019
ACEH	1.0163	0.9969	0.019
BCDFJL	1.1506	1.1298	0.021
CFGHKL	0.7811	0.7596	0.021
BDEFGHL	0.8765	0.8539	0.023
ABDEFGK	0.9931	0.9699	0.023
BEJL	0.9252	0.9011	0.024
BDEH	0.9811	0.9569	0.024
BFGHJL	1.1314	1.1071	0.024
ACL	0.8236	0.7991	0.024
CEKL	0.7695	0.7449	0.025
AEK	0.9109	0.8857	0.025
ABEGL	0.9211	0.8946	0.027
ACDEFHKL	0.8310	0.8042	0.027
ABCHJL	1.0219	0.9927	0.029
BCDEK	0.9555	0.9257	0.030
DEGHKL	0.8547	0.8222	0.032
BEFHKL	0.8782	0.8442	0.034
ACFHJKL	1.0408	1.0062	0.035
EGJK	1.1394	1.1040	0.035
ABCDFHJK	1.1930	1.1567	0.036
ADFH	0.9557	0.9158	0.040
BCDGJ	1.1767	1.1349	0.042
DHJL	1.0747	1.0326	0.042
BCEFL	0.8528	0.8069	0.046
ABCFKL	0.7993	0.7527	0.047
ADEG	0.9599	0.9120	0.048
BDL	0.8881	0.8391	0.049
ACDFGHJL	1.1167	1.0671	0.050
ABDEKL	0.7553	0.7049	0.050
ACDEFGJ	1.2539	1.2027	0.051
ABDFGHKL	0.8545	0.7996	0.055
CDFHL	0.9946	0.9384	0.056
ADEHJKL	0.9581	0.8984	0.060
ABCEFHK	0.9461	0.8850	0.061
CDJKL	0.8682	0.8069	0.061
BCDEFHJ	1.2097	1.1475	0.062
AEFHJ	1.2663	1.1875	0.079
CDFGJK	1.2110	1.1319	0.079
BCDFGHK	1.0238	0.9405	0.083
EFJKL	1.1261	1.0355	0.091

* INDICATES RESIDUAL MAGNITUDE EXCEEDS
2 (TWO) STANDARD DEVIATIONS

Table VII.3 (continued)

TREATMENT	MEAN OF OBSERVED VALUES	PREDICTED VALUE	RESIDUAL	
BDGHJK	1.1267	1.0347	0.092	
CEGHJ	1.1643	1.0655	0.099	
DFGHJ	1.3930	1.2942	0.099	
ABJKL	0.9469	0.8469	0.100	
ABCFGHJ	1.3566	1.2543	0.102	
BHJ	1.2654	1.1501	0.115	
BGKL	0.8779	0.7604	0.117	
DGK	0.9623	0.8411	0.121	
ABFGJK	1.2964	1.1718	0.125	
ACDEJL	1.0681	0.9411	0.127	*
BCEG	1.0017	0.8720	0.130	*
BCGHL	1.0529	0.9164	0.136	*

* INDICATES RESIDUAL MAGNITUDE EXCEEDS
2 (TWO) STANDARD DEVIATIONS

APPENDIX A

SAMPLE QUESTIONNAIRE

PURPOSE: THE PURPOSE OF THIS QUESTIONNAIRE IS TO OBTAIN YOUR ESTIMATE, AS A TANK COMMANDER IN COMBAT, OF THE THREAT POSED BY A DETECTED ENEMY ANTI-TANK SYSTEM IN VARIOUS COMBAT SITUATIONS, AND YOUR DECISION TO ENGAGE/NOT ENGAGE ASSOCIATED WITH THESE SITUATIONS. THE GOAL OF THIS SURVEY IS TO ESTIMATE THE RELATIVE IMPORTANCE WHICH A TANK COMMANDER PLACES ON THE VARIOUS FACTORS ASSOCIATED WITH THE TARGET SELECTION PROCESS. THIS QUESTIONNAIRE IS PART OF AN EFFORT BEING MADE BY U.S. ARMY OFFICERS AT THE U.S. NAVAL POSTGRADUATE SCHOOL TO DEVELOP A REALISTIC SIMULATION OF TANK COMBAT.

GENERAL: IN THE REMAINDER OF THIS QUESTIONNAIRE, YOU WILL BE ASKED TO PLACE YOURSELF IN THE ROLE OF A TANK COMMANDER IN COMBAT. YOU WILL BE PRESENTED 18 DIFFERENT SITUATIONS DESCRIBING A CONFRONTATION BETWEEN YOUR TANK AND A DETECTED ENEMY ANTI-TANK SYSTEM. THE FOLLOWING TWO RESPONSES WILL BE REQUIRED BASED ON THE INFORMATION GIVEN FOR EACH SITUATION.

1. YOUR ESTIMATE OF HOW CRITICAL THE DETECTED ENEMY SYSTEM IS TO YOUR SURVIVAL IN THE NEXT 30 SECONDS.

2. YOUR DECISION AS TO WHETHER YOU WOULD OR WOULD NOT IMMEDIATELY ENGAGE THE TARGET.

PLEASE RESPOND TO THE QUESTIONS ASKED IN ACCORDANCE WITH YOUR FEELING REGARDING THE SITUATION. THERE IS NO SUCH THING AS A RIGHT OR WRONG ANSWER TO ANY QUESTION. AS A TANK COMMANDER IN COMBAT, YOU WILL BE REQUIRED TO RAPIDLY ESTIMATE THE BATTLEFIELD SITUATION AND TO MAKE QUICK INDEPENDENT DECISIONS BASED ON THIS ESTIMATE. THEREFORE, WITH THIS IN MIND YOU SHOULD TAKE ONLY ENOUGH TIME TO FULLY UNDERSTAND EACH SITUATION PRESENTED AND THEN QUICKLY MAKE YOUR DECISIONS AND RECORD YOUR RESPONSES. ON THE ARMOR BATTLEFIELD, ONCE A DECISION IS MADE, THERE IS NO TURNING BACK, AND THEREFORE YOU ALSO SHOULD NOT CHANGE YOUR RESPONSES ONCE YOU HAVE MADE YOUR DECISIONS.

SITUATION: THE FOLLOWING GENERAL SITUATION IS PERTINENT FOR THE REMAINDER OF THIS QUESTIONNAIRE:

> FRIENDLY FORCES ARE PRESENTLY DEFENDING ON HIGH GROUND RUNNING NORTH/SOUTH WITH SUSPECTED ENEMY ATTACK FROM THE EAST. THE TANK COMPANY OF WHICH YOUR PLATOON IS A PART CONSISTS OF XM1 TANKS. YOUR PLATOON HAS BEEN GIVEN THE RESPONSIBILITY OF DEFENDING THE CENTRAL SECTOR FACING THE DIRECTION OF THE ASSUMED ENEMY FORCE LOCATION. YOUR OWN TANK IS POSITIONED IN THE CENTER OF THE PLATOON, WITH A 50-100 METER SPACING BETWEEN THE ELEMENTS OF THE PLATOON. YOU, AS ONE OF THE TANK COMMANDERS ON THE FORWARD LINE OF DEFENSE, HAVE BEEN GIVEN COMPLETE FREEDOM TO INITIATE AND RETURN FIRE IN ANY FUTURE ENGAGEMENT AS YOU SEE FIT BY YOUR ESTIMATE OF THE BATTLEFIELD SITUATION.

ASSUMPTIONS: IT IS ASSUMED THAT IN ALL SITUATIONS PRESENTED THAT YOU HAVE MADE POSITIVE DETECTION ON THE ENEMY VEHICLE IN QUESTION. BY THIS IS MEANT THAT YOU CAN PRESENTLY SEE THE TARGET AND THAT YOU CAN IDENTIFY HIM AS TANK T72, BMP,BRDM,ETC. IT IS ALSO ASSUMED THAT THE AMMUNITION THAT YOU HAVE ON BOARD IS OF THE COMMON BASIC VARIETY THAT WOULD BE CARRIED AS BASIC LOAD ON THE XM1.

TWO EXAMPLES AND REMARKS ON EACH ARE PRESENTED TO FAMILIARIZE YOU WITH THE TECHNIQUE IN WHICH THE VARIOUS SITUATIONS WILL BE PRESENTED.

PRIOR TO PRESENTING THESE EXAMPLES, IT IS NECESSARY TO DISCUSS SOME OF THE TERMS WHICH WILL BE USED IN DESCRIBING THE SITUATIONS. EACH SITUATION WILL BE DESCRIBED BY 10 FACTORS EACH AT TWO LEVELS. ALL OF THESE TERMS AND FACTORS ARE STRAIGHT-FORWARD WITH THE FOLLOWING POSSIBLE EXCEPTIONS:

1. ON BOARD ROUNDS REMAINING -- DESCRIBED AS EITHER 'ABOVE CRITICAL LEVEL' OR 'AT OR BELOW CRITICAL LEVEL'. THE CRITICAL LEVEL REFERRED TO HERE IS DEPENDENT UPON THE ACTUAL SITUATION AND DIFFERS AMONG INDIVIDUAL TANK COMMANDERS. FOR THIS PARTICULAR SURVEY, ASSUME THAT YOUR PLATOON HAS BEEN TOLD WHAT THIS CRITICAL LEVEL IS. SPECIFICALLY, FOR THE SAKE OF CONSERVING AMMUNITION, YOU HAVE BEEN INSTRUCTED TO BE PARTICULARLY CAUTIOUS ABOUT ENGAGING TARGETS WHEN YOUR ON BOARD ROUNDS REMAINING DROPS BELOW A PARTICULAR NUMBER. NOTE HERE THAT UNDER DIFFERENT SITUATIONS, THIS NUMBER COULD BE 5, 10, ETC. NOTE ALSO THAT THIS INSTRUCTION IN NO WAY PROHIBITS YOU FROM ENGAGING ANY ENEMY TARGET THAT YOU FEEL REASONABLY CAPABLE OF HITTING. HOWEVER, WHEN YOUR ON BOARD ROUNDS REMAINING DROPS BELOW THIS CRITICAL LEVEL, IT SHOULD BE OBVIOUS THAT YOU ARE VERY CLOSE TO RUNNING OUT OF AMMUNITION, A FACT THAT COULD BE VERY REAL ON THE FUTURE ARMOR BATTLEFIELD.

3. ANTICIPATED RESUPPLY -- DESCRIBED AS 'SOON' OR 'NOT SOON'. AGAIN THIS IS AN OPINION THAT DIFFERS AMONG INDIVIDUALS. HOWEVER, IT IS NOT UNREALISTIC TO ASSUME THAT IN AN ACTUAL BATTLE, THE MOST ACCURATE INDICATION OF THE NEXT SCHEDULED RESUPPLY WILL BE SOON OR NOT SOON. THIS PARTICULAR DESCRIPTION DOES LEAD TO SOME DEGREE OF CONFUSION. HOWEVER, IT IS OBVIOUS THAT IF YOUR ON BOARD ROUNDS REMAINING IS LOW AND ANTICIPATED RESUPPLY IS NOT SOON THAT THOSE FEW REMAINING ROUNDS ARE JUST THAT MUCH MORE CRITICAL TO YOU. EVEN IF THE ANTICIPATED RESUPPLY IS SOON, THERE WOULD STILL BE SOME WORRY CONCERNING THE ACTUAL RESUPPLY.

5. TARGET IS IN YOUR SECTOR OF RESPONSIBILITY? -- DESCRIBED AS 'YES' OR 'NO'. NOTE HERE THAT A TARGET OUTSIDE YOUR SECTOR OF RESPONSIBILITY DOES NOT PROHIBIT YOU FROM ENGAGING THE TARGET. SPECIFICALLY, YOU STILL HAVE COMPLETE FREEDOM TO ENGAGE ANY TARGET, AT ANY TIME, BASED ON YOUR ESTIMATE OF THE SITUATION.

8. SPEED OF TARGET -- DESCRIBED AS 'FAST' OR 'NOT FAST'. ANOTHER SUBJECTIVE DESCRIPTION WHICH WILL DIFFER AMONG TANK COMMANDERS WHEN OBSERVING AN ENEMY VEHICLE ON THE BATTLEFIELD. NOTE HERE THAT FAST COULD BE 20,30,OR 10 MPH DEPENDING ON ANY GIVEN BATTLEFIELD SITUATION. THE IDEA HERE IS TO BE AWARE THAT THERE IS A DIFFERENCE, AND AN ENEMY VEHICLE DESCRIBED AS MOVING FAST WILL OBVIOUSLY, IF NOT SLOWED, GET TO ITS FINAL DESTINATION BEFORE ONE THAT IS MOVING SLOW.

CONCERNING THE TWO RESPONSES THAT YOU WILL BE MAKING FOR EACH SITUATION. ONE IS 'YES' OR 'NO' AND AS SUCH SHOULD PRESENT NO DIFFICULTY. A REMARK WILL BE MADE CONCERNING THE FIRST RESPONSE REQUIRED. THIS QUESTION DEALS WITH YOUR FEELING BASED ON YOUR SITUATION AND THE OBSERVED SITUATION OF YOUR DETECTED ENEMY TARGET. YOU WILL BE ASKED THE FOLLOWING:

> GIVEN THE SITUATION PRESENTED ABOVE..
> HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL...

------+------+------+------+------+------+------+------+------+------
0 1 2 3 4 5 6 7 8 9 10

THIS QUESTION ASKS THAT YOU LIST THE DEGREE OF THREAT THAT YOU PERCEIVE FROM THE ENEMY TARGET AS DESCRIBED IN THE SITUATION. THE SCALE IS DEFINED AS FOLLOWS:

0 -- TARGET IS NOT A THREAT AT THE PRESENT TIME(I.E.IMMEDIATE TIME FRAME AND THE NEXT 30 SECONDS)

10 -- THE TARGET IS AN EXTREMELY CRITICAL THREAT TO YOUR SURVIVAL (I.E. IMMEDIATE TIME FRAME AND NEXT 30 SECONDS)

THE REQUIRED RESPONSE IS THAT YOU PLACE A HEAVY LINE AT THE POINT ON THE SCALE WHICH BEST IDENTIFIES THE THREAT PERCEIVED FOR THE SITUATION PRESENTED.

```
EXAMPLE 1.

              *************
              * SITUATION *
              *************

             ------------
            / YOUR TANK /
            ------------

ON BOARD ROUNDS REMAINING:  ABOVE CRITICAL LEVEL
YOUR CURRENT ACTIVITY:  STATIONARY/HULL DEFILADE
ANTICIPATED RESUPPLY:  NOT SOON

             --------------
            / YOUR TARGET /
            --------------

VEHICLE TYPE:  TANK T72
TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?:  YES
RANGE TO TARGET:  2350 METERS
TURRET ORIENTATION RELATIVE TO YOUR TANK:  POINTED AT YOU
SPEED OF TARGET:  NOT FAST
COVER/CONCEALMENT OF TARGET:  FULLY EXPOSED
TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?:  YES
--------------------------------------------------------------------------------

1.  GIVEN THE SITUATION PRESENTED ABOVE...
    HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

       *----+----+----+----+----+----+---|+----+----+----*
       0    1    2    3    4    5    6    7    8    9    10

2.  GIVEN THE SITUATION PRESENTED ABOVE,
    WOULD YOU ENGAGE THE TARGET AT THIS TIME?

      ( ) YES                         (X) NO
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

REMARKS CONCERNING EXAMPLE 1.  IT IS OBVIOUS THAT THE TANK COMMANDER IN THIS
CASE FELT THAT THE ENEMY TANK DID POSE A SERIOUS, ALTHOUGH NOT YET EXTREME,
THREAT TO HIS SURVIVAL.  THE TANK COMMANDER ALSO CHOSE NOT TO ENGAGE THE TARGET
AT THIS TIME, PROBABLY DUE TO THE PRESENT EXTENDED RANGE BETWEEN HIS TANK AND
HIS TARGET.  A REMINDER HERE THAT THIS ESTIMATE AND DECISION TO ENGAGE/NOT
ENGAGE WAS THIS TANK COMMANDER'S DECISION BASED ON HOW HE FELT ABOUT THIS
PARTICULAR SITUATION.  THE DECISION NOTED HERE MAY DIFFER GREATLY FROM THE
DECISION YOU WOULD HAVE MADE GIVEN THIS SITUATION.  A REMINDER AGAIN THAT THERE
ARE NO RIGHT OR WRONG ANSWERS.
```

EXAMPLE 2.

```
*************
* SITUATION *
*************
```

/ YOUR TANK /

ON BOARD ROUNDS REMAINING: AT OR BELOW CRITICAL LEVEL
YOUR CURRENT ACTIVITY: STATIONARY/HULL DEFILADE
ANTICIPATED RESUPPLY: NOT SOON

/ YOUR TARGET /

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER
TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: NO
RANGE TO TARGET: 1050 METERS
TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AWAY FROM YOU
SPEED OF TARGET: NOT FAST
COVER/CONCEALMENT OF TARGET: FULLY EXPOSED
TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
                                          |
*----+----+----+----+----+----+----+--|--+----+----*
0    1    2    3    4    5    6    7  |  8    9    10
                                          |
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

   ☒ YES ☐ NO

REMARKS ON EXAMPLE 2. THE TANK COMMANDER IN THIS SITUATION AGAIN RATED THE THE DETECTED ENEMY TARGET AS A SERIOUS THREAT TO HIS SURVIVAL. NOTE HERE THAT ALTHOUGH THE ENEMY VEHICLE WAS SIGNIFICANTLY CLOSER TO THE FRIENDLY TANK'S POSITION, THE TANK COMMANDER'S DECISION REFLECTS ABOUT THE SAME DEGREE OF THREAT AS WAS REFLECTED FOR THE SITUATION IN EXAMPLE 1. IT IS POSSIBLE THAT THIS TANK COMMANDER IS HIGHLY CONFIDENT OF HIS CAPABILITY OF DESTROYING THE TARGET. NOTE ALSO THAT ALTHOUGH THE TARGET IS OUTSIDE HIS SECTOR OF RESPONSIBILITY, AND THAT THE TANK COMMANDER IS CRITICALLY SHORT OF AMMUNITION, HIS DECISION IS TO IMMEDIATELY ENGAGE THE TARGET. AGAIN YOU ARE REMINDED THAT THIS DECISION MAY DIFFER GREATLY FROM THE DECISION THAT YOU WOULD HAVE MADE GIVEN THIS SITUATION. AGAIN THERE ARE NO RIGHT OR WRONG ANSWERS. IT IS YOUR INDEPENDENT DECISION THAT WE ARE SEEKING.

```
*****************                         (1)              1/ 1
* SITUATION   1 *
*****************
```

/ YOUR TANK /

ON BOARD ROUNDS REMAINING: ABOVE CRITICAL LEVEL

YOUR CURRENT ACTIVITY: STATIONARY/HULL DEFILADE

ANTICIPATED RESUPPLY: SOON

/ YOUR TARGET /

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: NO

RANGE TO TARGET: 1050 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AWAY FROM YOU

SPEED OF TARGET: NOT FAST

COVER/CONCEALMENT OF TARGET: FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: NO

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

( ) YES   ( ) NO

```
*****************                    ABCDEFGH          1/ 2
* SITUATION   2 *
*****************
```

```
 ------------
/ YOUR TANK /
------------
```

ON BOARD ROUNDS REMAINING: AT OR BELOW CRITICAL LEVEL

YOUR CURRENT ACTIVITY: MOVING/PARTIALLY EXPOSED

ANTICIPATED RESUPPLY: NOT SOON

```
 --------------
/ YOUR TARGET /
--------------
```

VEHICLE TYPE: TANK T72

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: YES

RANGE TO TARGET: 1050 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AWAY FROM YOU

SPEED OF TARGET: FAST

COVER/CONCEALMENT OF TARGET: NOT FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

(   ) YES   (   ) NO

```
*****************
* SITUATION   3 *
*****************
```

DEFG J L 1/ 3

```
 ------------
/ YOUR TANK /
 ------------
```

ON BOARD ROUNDS REMAINING: ABOVE CRITICAL LEVEL

YOUR CURRENT ACTIVITY: STATIONARY/HULL DEFILADE

ANTICIPATED RESUPPLY: SOON

```
 --------------
/ YOUR TARGET /
 --------------
```

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: YES

RANGE TO TARGET: 2350 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AT YOU

SPEED OF TARGET: FAST

COVER/CONCEALMENT OF TARGET: NOT FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

( ) YES ( ) NO

```
*****************                  A CD  G  KL      1/ 7
* SITUATION   7 *
*****************
```

/ YOUR TANK /

ON BOARD ROUNDS REMAINING: AT OR BELOW CRITICAL LEVEL

YOUR CURRENT ACTIVITY: STATIONARY/HULL DEFILADE

ANTICIPATED RESUPPLY: NOT SOON

/ YOUR TARGET /

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: NO

RANGE TO TARGET: 3000 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AWAY FROM YOU

SPEED OF TARGET: FAST

COVER/CONCEALMENT OF TARGET: FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

( ) YES   ( ) NO

```
*****************
* SITUATION  11 *
*****************
```

AB E G L 1/11

/ YOUR TANK /

ON BOARD ROUNDS REMAINING: AT OR BELOW CRITICAL LEVEL
YOUR CURRENT ACTIVITY: MOVING/PARTIALLY EXPOSED
ANTICIPATED RESUPPLY: SOON

/ YOUR TARGET /

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER
TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: NO
RANGE TO TARGET: 2350 METERS
TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AWAY FROM YOU
SPEED OF TARGET: NOT FAST
COVER/CONCEALMENT OF TARGET: NOT FULLY EXPOSED
TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
WOULD YOU ENGAGE THE TARGET AT THIS TIME?

( ) YES ( ) NO

```
*****************          BC  FG JKL     1/15
* SITUATION  15 *
*****************
```

```
 ------------
/ YOUR TANK /
-------------
```

ON BOARD ROUNDS REMAINING: ABOVE CRITICAL LEVEL

YOUR CURRENT ACTIVITY: MOVING/PARTIALLY EXPOSED

ANTICIPATED RESUPPLY: NOT SOON

```
 --------------
/ YOUR TARGET /
--------------
```

VEHICLE TYPE: BMP/BRDM W/SAGGER/SWATTER

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: YES

RANGE TO TARGET: 3000 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AT YOU

SPEED OF TARGET: NOT FAST

COVER/CONCEALMENT OF TARGET: FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: YES

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

(   ) YES   (   ) NO

```
*****************                    A  DE  HJKL     1/16
* SITUATION  16 *
*****************
```

/ YOUR TANK /

ON BOARD ROUNDS REMAINING: AT OR BELOW CRITICAL LEVEL

YOUR CURRENT ACTIVITY: STATIONARY/HULL DEFILADE

ANTICIPATED RESUPPLY: SOON

/ YOUR TARGET /

VEHICLE TYPE: TANK T72

TARGET IS IN YOUR SECTOR OF RESPONSIBILITY?: NO

RANGE TO TARGET: 3000 METERS

TURRET ORIENTATION RELATIVE TO YOUR TANK: POINTED AT YOU

SPEED OF TARGET: FAST

COVER/CONCEALMENT OF TARGET: NOT FULLY EXPOSED

TARGET HAS BEEN DETECTED FIRING IN THE LAST MINUTE?: NO

---

1. GIVEN THE SITUATION PRESENTED ABOVE...
   HOW CRITICAL IS THIS TARGET TO YOUR SURVIVAL..

```
*-----+-----+-----+-----+-----+-----+-----+-----+-----+-----*
0     1     2     3     4     5     6     7     8     9     10
```

2. GIVEN THE SITUATION PRESENTED ABOVE,
   WOULD YOU ENGAGE THE TARGET AT THIS TIME?

(   ) YES   (   ) NO

CRITIQUE AND PERSONAL HISTORY FORM

PLEASE COMPLETE THE FOLLOWING FORM BY ENTERING THE APPROPRIATE RESPONSES:

1. TIME ON ACTIVE DUTY: (   ) YEARS (   ) MONTHS

1A. TIME SPENT AS A TANK COMMANDER: (   ) YEARS (   ) MONTHS

2. PRESENT RANK:

3. HOW FAMILIAR ARE YOU WITH THE XM1?

(   ) HANDS ON EXPERIENCE

(   ) NO HANDS ON EXPERIENCE, BUT VERY KNOWLEDGEABLE OF ITS CAPABILITIES

(   ) MINIMAL KNOWLEDGE

(   ) NO KNOWLEDGE

4. DID YOUR AWARENESS OF THE INCREASED CAPABILITIES OF THE XM1 CAUSE YOU TO MAKE DECISIONS THAT YOU WOULD HAVE OTHERWISE MADE HAD YOUR UNIT HAD M60 TANKS.

(   ) YES (   ) NO

(   ) NOT APPLICABLE

5. HOW FAMILIAR ARE YOU WITH THE M60A3?

(   ) HANDS ON EXPERIENCE

(   ) NO HANDS ON EXPERIENCE, BUT VERY KNOWLEDGEABLE OF ITS CAPABILITIES

(   ) MINIMAL KNOWLEDGE

(   ) NO KNOWLEDGE

5A. TOTAL EXPERIENCE ON EITHER THE XM1 OR M60A3: (   ) YEARS (   ) MONTHS

6. WERE THE SITUATIONS PRESENTED UNDERSTANDABLE? (   ) YES (   ) NO

COMMENTS:

7. WOULD YOU SAY THAT THE SITUATIONS WERE REALISTIC OF AN ARMOR BATTLEFIELD?

(   ) YES (   ) NO

COMMENTS:

8. DO YOU FEEL THAT THIS QUESTIONNAIRE WAS A WORTHWILE LEARNING EXPERIENCE?

(   ) YES (   ) NO

COMMENTS:

9. PLEASE MAKE ANY ADDITIONAL COMMENTS THAT YOU FEEL APPROPRIATE AT THIS TIME:

APPENDIX B

SUMMARY OF CRITIQUE AND PERSONAL HISTORY FORMS

1. and 2. Personnel Surveyed in Sample

Rank	#	Average Time Spent on Active Duty Years / Months	Average Time Spent as a Tank Commander Years / Months
E5	12	4 / 7	1 / 9
E6	26	9 / 0	4 / 2
E7	14	15 / 10	9 / 0
O1	1	1 / 5	1 / 1
O2	1	4 / 0	2 / 0
O3	9	8 / 7	2 / 5
O4	1	12 / 5	1 / 3
TOTAL	64	9 / 7	4 / 1

3. How familiar are you with the XM1?

(11) hands on experience

(9) no hands on experience but very knowledgeable of its capabilities

(25) minimal knowledge

(19) no knowledge

4. Did your awareness of the increased capabilities of the XM1 cause you to make decisions that you would have otherwise made had your unit had M60 tanks?

(24) Yes (29) No (11) Not Applicable

5. How familiar are you with the M60A3?

(12) hands on experience

(11) no hands on experience, but very knowledgeable of its capabilities

(20) minimal knowledge

(21) no knowledge

5.a. Total experience on either the XM1 or the M60A3?

Eleven personnel had an average of 6.5 months experience on the XM1.

Twelve personnel had an average of 4 months experience on the M60A3.

6. Were the situations presented understandable?

(58) Yes (4) No

Two personnel chose not to answer.

7. Would you say that the situations were realistic of an armor battlefield?

(51) Yes (10) No

Three personnel chose not to answer.

8. Do you feel that this questionnaire was a worthwhile learning experience?

(46) Yes (15) No

Three personnel chose not to answer

Individuals were asked to make general comments in regard to the questionnaire and specifically in regard to questions 6, 7, and 8 listed above. All comments are listed below. The great majority of these are quoted directly from the critique sheets. Others have been slightly modified

to make them more presentable. In all cases every effort was made to preserve the integrity of the individual making the comment and to convey the correct meaning implied by the comment.

6. Yes -- They were vague. The stress factor could vary decisions on an actual battlefield.
6. Yes -- This was an enjoyable questionnaire. There should be even more emphasis on time allotted to answer each question.
6. No -- Direction vehicle is moving is a very important factor in determining whether to engage or not to engage. A target moving in or out or away from your sector is very important. You may want to withhold an engagement and notify adjacent vehicles or elements responsible for that sector.
6. Yes -- I question the frequency of moving, moving and would consider coming to a halt on a long-range fast-moving target.
6. Yes -- The situations were extremely clear although extremely simplified.
7. Yes -- If a gun tube is pointed at me and if it is a major threat, I'm going to shoot. There is no room for 'maybes' on the battlefield.
7. No answer -- I have never been on a battlefield so I cannot give a yes or no answer.

7. No -- On many of the BMPs and BRDMs I would have used the 50 Cal Machine Gun.

7. Yes -- The situations were particularly realistic of the European battlefield.

7. No -- I would expect numerous armored vehicles to be in my sector, all aiming at me. This is what this questionnaire should have incorporated.

7. No -- Ranges were probably too long to observe.

7. Yes -- Some of the situations were close.

7. Yes -- More various ranges should have been included. Too many vehicles were observed shooting prior to the present situation. This made one more willing to engage.

7. No -- The situations presented here were all one on one. On the modern battlefield we can expect to be greatly outnumbered.

7. Yes -- However, in the European situation, the ranges will probably be generally closer and the situations much more critical.

7. Yes -- In my position other vehicles besides vehicles capable of killing me would be high priority targets, i.e. command tracks, anti-air weapons, etc.

7. Yes -- There should have been some representation of artillery smoke and tactical air being used by the attacking force.

7. No -- Ranges were too far in many cases.

7. Yes -- with the exception that there was nothing said about what the battlefield condition was: light, time of day, weather, observation and fields of fire, size of OPFORS, etc.; with more information I may have answered differently.

8. Yes -- Had I been critiqued as to something which I may have overlooked, or failed to consider, I would have answered yes. No critique or comparison is being made, no answers are being changed, whatever I do on the real battlefield is probably better than hesitating or doing nothing.

8. Yes -- However, it was designed for an XM1. The M60A1 is still the main battle tank for most 19E's.

8. Yes -- Somewhat, it makes one stop and think when presented similar situations with different factors being varied.

8. No -- It did make one think what you would do, but without any feedback there is no learning experience.

8. Yes -- As far as making a snap decision was concerned, the situations were extremely well written and provide an excellent practice for this type of lesson and critique.

8. Yes -- It made one consider rounds on board, something not usually thought of.

8. Yes -- It was interesting, but based on the exact number of actual rounds remaining, some of my answers might have changed.

8. Yes -- Publish the results in Armor Magazine. It would be very enlightening and educational.

9. Some mention of ammunition types on board the XM1, if different from the M60, would have perhaps influenced my decision to fire.

9. If I had artillery on call, as I probably would, I would suppress BRDM's at 3000 meters by field artillery.

9. Some answers may seem to contradict others. However, picturing myself on the battlefield I know exactly what I would do and how to go about doing it.

9. The survey should have been based on the M60A1, not the XM1, simply because it is the tank we presently have fielded.

9. I feel as an XM1 platoon sergeant that I can do much more than if I were with the M60A1.

9. I have to be there at the time in order to make a correct decision.

9. Knowing the capability of threat armor and anti-armor vehicles, I felt that none of the situations were of the 10 (extremely critical) rating. Also, the direction of movement of enemy vehicles should have been noted.

9. Not enough information on XM1 capabilities was given. Also there was no mention of terrain, support available, defensive position, attack, etc.

9. I was not thinking XM1 during the questionnaire, only rounds remaining and my chances of hitting a target at different ranges.

9. The ranges in this survey were not applicable from my own experiences in Europe, where I had a maximum range of 800 to 1000 meters. Thus in that situation every target was a great threat and I don't think I would have any choice but to engage and to hope that our resupply were soon in all classes.

COMPUTER PROGRAMS

```
C ***********************************************************
C *   PROGRAM TO ANALYZE A DESIGN OF THE FORM 2**(N-P)
C *   WITH AT LEAST TWO MEASUREMENTS PER CELL.
C ***********************************************************
C
C
C THIS PROGRAM IS DESIGNED TO CALCULATE THE GENERAL ANOVA
C FOR ANY 2**(N-P) FACTORIAL DESIGN.  IT IS PARTICULARLY
C TAILORED IN ITS TERMINOLOGY AND DATA INPUT FOR THOSE
C FRACTIONAL FACTORIAL PLANS PRESENTED IN THE NATIONAL
C BUREAU OF STANDARDS MATHEMATICS SERIES, VOLUME 48,1957,
C 'FRACTIONAL FACTORIAL EXPERIMENT DESIGNS FOR FACTORS
C AT TWO LEVELS'.  HOWEVER, IT IS ALSO EQUALLY APPLICABLE
C FOR A FULL FACTORIAL 2**N DESIGN, WITH OR WITHOUT
C BLOCK CONFOUNDING.  THIS PROGRAM WILL, WHEN OPTION 2 OR
C 3 IS SELECTED, PRODUCE A FULL ANALYSIS OF REGRESSION,
C TO INCLUDE THE GENERAL ANOVA WITH STATISTICS CONCERNING
C PREDICTED VERSUS OBSERVED VALUES, AND ANOVA ON EACH
C REGRESSION COEFFICIENT.  BASIS FOR DELETION FROM THE
C MODEL IS DESIGNATED BY THE INPUT VARIABLE 'ALPHA'.  IT
C SHOULD BE NOTED HERE THAT ALL VARIABLES LISTED
C (DATA GROUP III) CAN BE FORCED INTO THE MODEL BY SETTING
C 'ALPHA = 1.0'.  ALL CALCULATIONS ARE PERFORMED IN DOUBLE
C PRECISION.  FACTORS/TREATMENTS ARE DESIGNATED BY THE
C LETTERS -- A,B,C,D,E,F,G,H,J,K,L,M.
C
C
C THE PROGRAM WILL ALSO CALCULATE AND DISPLAY PERTINENT
C STATISTICS THAT ARE COMMONLY USED IN TESTING THE BASIC
C ASSUMPTIONS OF THE GENERAL LINEAR MODEL.  THESE
C STATISTICS ARE:  BARTLETT'S TEST STATISTIC (FOR TESTING
C THAT INDIVIDUAL CELL VARIANCES ARE HOMOGENEOUS), THE
C F-MAX RATIO(ANOTHER COMMONLY USED STATISTIC  IN TESTING
C FOR HOMOGENEITY OF VARIANCE), AND THE KOLMOGOROV SMIRNOV
C STATISTIC(FOR TESTING THAT THE OBSERVATIONS ARE NORMALLY
C DISTRIBUTED).  THE USER OF THIS PROGRAM IS CAUTIONED THAT
C THE F-MAX RATIO SHOULD BE USED IN LIEU OF THE BARTLETT
C TEST STATISTIC FOR SMALL 'N'.  CONVERSELY, FOR LARGE 'N',
C BARLETT'S TEST STATISTIC SHOULD BE USED.  THE PROGRAM
C WILL PRINT THE FOLLOWING MESSAGE WHEN AN INDIVIDUAL CELL
C VARIANCE IS CALCULATED TO BE 0.0 (ZERO):
C
C  ***BARTLETT TEST STATISTIC AND F-MAX RATIO CANNOT BE
C                               CALCULATED***
C  SAMPLE VARIANCE = 0.0,    CELL ---   (TREATMENT CODE
C                                           DISPLAYED)
C
C
C
C THE FOLLOWING RESTRICTIONS APPLY TO THE USE OF THIS
C PROGRAM:
C
C          1.   'N' IS LESS THAN 13
C          2.   NUMBER OF REPLICATIONS IS GREATER THAN 1
C          3.   ALL FACTORS ARE FIXED
C          4.   NO MISSING OBSERVATIONS
C
C
C    PROGRAM USAGE:
C
C     CALL ZNOVA(BRT,TTOT,DUMMY,ALPHA,IOPT,NN,NP,NB,NTB,
C                   NR,NTS,NODC,IALIAS,ITA)
C
C WHERE THE ABOVE ARGUMENTS ARE DEFINED AS FOLLOWS:
C
C  NN -- INTEGER VARIABLE, EQUALS NUMBER OF FACTORS/
C          TREATMENTS. I.E.CORRESPONDS TO 'N' IN 2**(N-P).
C  NP -- INTEGER VARIABLE,CORRESPONDS TO 'P' IN 2**(N-P).
```

```
C  NR -- INTEGER VARIABLE, EQUALS NUMBER OF REPLICATIONS.
C  NB -- INTEGER VARIABLE,  EQUALS NUMBER OF BLOCKS.
C  NTB -- INTEGER VARIABLE, EQUALS NUMBER OF TREATMENT
C           COMBINATIONS PER BLOCK.
C  NTS -- INTEGER VARIABLE, EQUALS NUMBER OF TREATMENT
C           COMBINATIONS PER REPLICATION.  I.E.2**(NN-NP)
C  NAS -- INTEGER VARIABLE, EQUALS 1 (ONE) OR NUMBER OF
C           DEFINING CONTRASTS DESIGNATED BY SIX OR FEWER
C           LETTERS.(WHICHEVER IS GREATER)
C  NODC -- INTEGER VARIABLE, EQUALS 1 (ONE) IF THE DESIGN
C            IS A FULL FACTORIAL.(I.E. NP=0)
C          EQUALS 0 (ZERO) IF THE DESIGN TO BE ANALYZED
C            IS A FRACTIONAL FACTORIAL.  (I.E. NP IS
C                                         GREATER THAN 0)
C  IOPT -- INTEGER VARIABLE DESIGNATING THE DESIRED
C            ANALYSIS OPTION, WHERE:
C
C        IOPT=1  YIELDS ANALYSIS OF TREATMENTS ONLY.
C        IOPT=2  YIELDS ANALYSIS OF REGRESSION ONLY.
C        IOPT=3  YIELDS ANALYSIS OF BOTH TREATMENTS AND
C                        REGRESSION.
C
C  ALPHA -- REAL INPUT VARIABLE DESIGNATING THE LEVEL OF
C             SIGNIFICANCE FOR THE DELETION OF TERMS FROM
C             THE MODEL, IS CUSTOMARILY .05.  ALPHA MUST
C             BE INITIALIZED REGARDLESS OF THE OPTION
C             CHOSEN.
C
C  BRT -- REAL*8 WORK ARRAY DIMENSIONED AS BRT(NB,NTB,NR)
C  TTOT -- REAL*8 WORK ARRAY DIMENSIONED AS TTOT(NTS,3)
C          ON OUTPUT, TTOT(I,1) CONTAINS THE MEAN OF
C              OBSERVATIONS FOR EACH TREATMENT COMBINATION.
C            TTOT(I,2) CONTAINS THE PREDICTED VALUE FOR
C              EACH TREATMENT COMBINATION.
C            TTOT(I,3) CONTAINS THE RESIDUALS OF PREDICTED
C              VERSUS THE MEAN OF OBSERVATIONS FOR EACH
C              TREATMENT COMBINATION.
C  DUMMY -- REAL*4 WORK ARRAY DIMENSIONED AS DUMMY(NTS,4)
C  ITA -- INTEGER*2 WORK ARRAY DIMENSIONED AS ITA(NTS,NN)
C  IALIAS -- INTEGER*2 WORK ARRAY DIMENSIONED AS
C            IALIAS(NAS,NN)
C
C
C
C ERROR CODES ARE AS FOLLOWS:
C
C  ERROR = 1  INDICATES THAT THE NUMBER OF TREATMENT
C              COMBINATIONS READ (DATA GROUP I)
C              DOES NOT = 2**(N-P).
C
C  ERROR = 2  INDICATES THE NUMBER OF DEFINING CONTRASTS
C              READ (DATA GROUP II) EXCEEDS 'NAS' AS
C              SPECIFIED IN THE MAIN PROGRAM.
C
C  ERROR = 3  ****  INDICATES THAT AN IMPROPER CONTRAST
C              WAS ENCOUNTERED UPON ATTEMPTING TO CALCULATE
C              THE SUM OF SQUARES FOR **** (DATA GROUP III).
C              THIS IS MOST PROBABLY CAUSED BY IMPROPER
C              DATA INPUT IN TYPING TREATMENT CODES IN
C              DATA GROUP I.
C
C  ERROR = 4  INDICATES THAT THE CUMULATIVE SUM OF SQUARES
C              FOR FACTORIAL EFFECTS LISTED IN DATA
C              GROUP III EXCEEDS THE TREATMENT SUM OF
C              SQUARES.
C              THIS IS MOST PROBABLY CAUSED BY ALIASED
C              EFFECTS BEING INCLUDED ON TWO OR MORE DATA
C              CARDS IN DATA GROUP III, THUS CAUSING THE
C              SUM OF SQUARES DUE TO THIS EFFECT TO BE
C              COUNTED MORE THAN ONCE.
```

```
C DATA INPUT IS ACCOMPLISHED IN THREE GROUPS AS FOLLOWS:
C NOTE THAT IN THE DATA DECK, EACH OF THESE DATA GROUPS IS
C FOLLOWED BY THE FOLLOWING DATA CARD:
C
C    CC    1234567890123456789012345678901234567890
C          0000000000000000000000000000000000000000
C            (ZERO'S)
C
C 1. DATA GROUP I  LISTS BLOCK NUMBER, POSITION WITHIN BLOCK
C NUMBER, AND TREATMENT CODE ON CARD 1; AND OBSERVATIONS
C ON CARD 2.
C
C    FORMATS USED ARE:
C    FOR CARD 1 -- **** FORMAT(2I5,10X,12A1)
C    FOR CARD 2 -- **** FORMAT(15D10.5)
C
C
C EXAMPLE WHERE TREATMENT CODE IS 'ACEGH',BLOCK NO. IS 3,
C POSITION W/BLOCK IS 8, 2 OBSERVATIONS ARE 200.45 & 235.67.
C
C       CC    1234567890123456789012345678901234567890123456789
C   CARD 1        3    8           ACEGH
C   CARD 2    200.45    235.67
C
C
C 2. DATA GROUP II  LISTS ALL DEFINING CONTRASTS WITH
C 6 OR FEWER LETTERS.
C
C    FORMAT USED IS   **** FORMAT(6A1)
C
C EXAMPLE WHERE DEFINING CONTRAST IS AEGHJK.
C
C   CC 1234567890123456789012345678901234567890
C      AEGHJK
C
C 3. DATA GROUP III LISTS ALL FACTORIAL EFFECTS  (NOT
C TO EXCEED 4-LEVEL INTERACTIONS) WHICH YOU DESIRE TO
C EVALUATE IN THE ANOVA..
C
C    FORMAT USED IS  **** FORMAT(4A1) AND INPUT IS AS
C    SHOWN ABOVE.
C
C TO DEMONSTRATE DATA INPUT, THE FOLLOWING EXAMPLES ARE
C PRESENTED:
C
C
C EXAMPLE 1:  2**(6-2) WITH 2 REPLICATIONS
C              (2 OBSERVATIONS PER CELL)
C             IN 4 BLOCKS OF 4 TREATMENT COMBINATIONS EACH
C            ( 1/4 REPLICATION OF 6 FACTORS IN 4 BLOCKS OF 4
C               TREATMENT COMBINATIONS)
C
C FACTORS: A,B,C,D,E,F
C I=ABCD=ABEF=CDEG  (DEFINING CONTRASTS)
C
C                                BLOCKS
C                     1       2       3     4
C POSITION W/BLOCK
C         1          (1)    ABCDEF   ACF   BDE
C         2          ABCD     EF     BDF   ACE
C         3          ABEF     CD     BCE   ADF
C         4          CDEF     AB     ADE   BCF
C
C OBSERVATIONS:
C         TRT. COMBINATIONS         REP I         REP II
C                (1)                 14.1           16.2
C               ABCD                 21.2           32.5
C               ABEF                 35.6           45.1
C              ......               ......         ......
C              ......               ......         ......
C               BCF                  61.3           72.6
C
```

```
C  MAIN PROGRAM DECK WOULD BE AS FOLLOWS:
C
C     REAL*8 BRT(4,4,2),TTOT(16,3)
C     REAL*4 DUMMY(16,4)
C     INTEGER*2 ITA(16,6),IALIAS(3,6)
C     NN=6
C     NP=2
C     NB=4
C     NR=2
C     NTB=4
C     NTS=16
C     NAS=3
C     NODC=0
C     IOPT=3
C     ALPHA=.05
C     CALL ZNOVA(BRT,TTOT,DUMMY,ALPHA,IOPT,NN,NP,NB,NTB,
C    *NR,NTS,NODC,NAS,IALIAS,ITA)
C     STOP
C     END
C
C DATA DECK WOULD BE AS FOLLOWS:
C
C                                  CC 123456789012345678
C                                      ------------------
C                                     /000000000000000000
C                                    ....................
C                                   .....................
C                                  ----------------------
C                                 /B
C                                 -----------------------
C                               /A
C                               -------------------------
C                              /000000000000000000000000
C                              -------------------------
C                            /CDEG
C                            ----------------------------
C                          /ABEF
C                          ------------------------------
C                        /ABCD
C                        --------------------------------
C                      /0000000000000000000000000000000
C                      ----------------------------------
C                    /61.3     72.6
C                    ------------------------------------
C                  /   4    4          BCF
C                  .....................................
C                 ......................................
C                ---------------------------------------
C               /21.2     32.5
C               ----------------------------------------
C             /    1    2          ABCD
C             ------------------------------------------
C           /14.1     16.2
C           --------------------------------------------
C  CARD 1  /    1    1          (1)
C
C
C
C   EXAMPLE 2:  2**2 FULL FACTORIAL (WITH 3 OBSERVATIONS
C             PER CELL AND NO BLOCK CONFOUNDING)
C
C   FACTORS:  A,B
C
C                        BLOCK
C                          1
C   POSITION W/BLOCK
C         1               (1)
C         2                A
C         3                B
C         4                AB
```

```
C  OBSERVATIONS:
C
C      TRT.COMBINATION         REP I      REP II      REP III
C           (1)                 6.3        7.1          6.7
C            A                  4.8        5.2          6.3
C            B                  7.4        7.5          8.1
C           AB                  5.6        6.2          7.1
C
C
C  MAIN PROGRAM DECK WOULD BE AS FOLLOWS:
C
C      REAL*8 BRT(1,4,3),TTOT(4,3)
C      REAL*4 DUMMY(4,4)
C      INTEGER*2 IALIAS(1,2),ITA(4,2)
C      NN=2
C      NP=0
C      NB=1
C      NTB=4
C      NR=3
C      NAS=1
C      NODC=1
C      IOPT=1
C      ALPHA=.05
C      CALL ZNOVA(BRT,TTOT,DUMMY,ALPHA,IOPT,NN,NP,NB,NTB,
C     *NR,NTS,NODC,NAS,IALIAS,ITA)
C      STOP
C      END
C
C
C  DATA DECK WOULD BE AS FOLLOWS:
C
C                                     CC     1234567890123456789012
C                                           ----------------------
C                                          /0000000000000000000000
C                                         ------------------------
C                                       /AB
C                                      ---------------------------
C                                     /B
C                                    -----------------------------
C                                   /A
C                                  -------------------------------
C                                 /0000000000000000000000000000000
C                                --------------------------------
C                               /00000000000000000000000000000000
C                              ----------------------------------
C                             /5.6        6.2        7.1
C                            --------------------------------------
C                           /     1    4              AB
C                          .........................................
C                         ..........................................
C                        --------------------------------------------
C                       /6.3         7.1         6.7
C                      ----------------------------------------------
C        CARD 1       /     1     1           (1)
C
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  *   DESIGNED & PROGRAMMED BY BROUSSARD,G   N P S   1979
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
        MAIN PROGRAM
      REAL*8 BRT(8,16,8),TTOT(128,3)
      REAL*4 DUMMY(128,4)
      INTEGER*2 ITA(128,11),IALIAS(12,11)
      NN=11
      NP=4
      NB=8
      NTB=16
      NR=8
      NTS=128
      NAS=12
      NODC=0
      IOPT=3
      ALPHA=.05
      CALL ZNOVA(BRT,TTOT,DUMMY,ALPHA,IOPT,
     *NN,NP,NB,NTB,NR,NTS,NODC,NAS,IALIAS,ITA)
      STOP
      END

      SUBROUTINE ZNOVA(XBT,TTOT,DUMMY,ALPHA,IOPT,
     *NN,NP,NB,NTB,NR,NTS,NODC,NAS,IALIAS,ITA)
      IMPLICIT REAL*8(O-Z)
      DIMENSION TTOT(NTS,3),XDUM(12),XBT(NB,NTB,NR),
     *BASE(12),DUMMY(NTS,4),CODE(14)
      INTEGER*2 INDEX(12),IDENT(4),ITA(NTS,NN),
     *IALIAS(NAS,NN)
      DATA KX/0/,KN/0/,TOT/0.0D0/,TSQ/0.0D0/,ZPURE/0.0D0/
      DATA CODE/'A','B','C','D','E','F','G','H','J','K','L',
     *                                   'M',' ','*'/
      DATA AZERO/'0'/,FLAG/9999.0/,FLAG1/0.0/,S2/0.0D0/
      DATA S21/0.0D0/,SMIN/999.0D0/,SMAX/-999.0D0/
      IALIAS(1,1)=0
      NR1=NR-1
      NTS1=NTS-1
900   FORMAT(2I5,10X,15A1)
901   FORMAT(////1X,10X,'ERROR =  ',I2,4X,15A1)
902   FORMAT(15D10.5)
904   FORMAT('1')
905   FORMAT(//1X,T20,'*** BARTLETT TEST STATISTIC & F MAX
     *RATIO CANNOT BE CALCULATED',/1X,T20,'SAMPLE VARIANCE =
     *0.0,       CELL: ',12A1)
      WRITE(6,904)
5     READ(5,900)IB,IP,(BASE(IX),IX=1,NN)
      IF(BASE(1).EQ.AZERO) GO TO 50
      READ(5,902) (XDUM(K),K=1,NR)
      KN=KN+1
      SI2=0.0D0
      X=0.0D0
      DO 20 J=1,NR
C   TRANSFORMATION CARD GOES HERE  I.E.   XDUM(J)=F(XDUM(J))
      XDUM(J)=DARSIN(DSQRT(XDUM(J)))
      X=X+XDUM(J)
      SI2=SI2+(XDUM(J))**2
      XBT(IB,IP,J)=XDUM(J)
20    CONTINUE
      TSQ=TSQ+SI2
      SI2=SI2-X**2/DFLOAT(NR)
      IF(SI2.GT.0.0D0) GO TO 23
      WRITE(6,905) (BASE(JKX),JKX=1,NN)
      FLAG1=1.0
      GO TO 24
23    S2=S2+DLOG10(SI2/DFLOAT(NR1))
      S21=S21+SI2/DFLOAT(NR1)
      IF(SI2.GT.SMAX) SMAX=SI2
      IF(SI2.LT.SMIN) SMIN=SI2
24    TTOT(KN,1)=X
      TOT=TOT+X
      KS=1
      KCOUNT=0
21    KCOUNT=KCOUNT+1
```

```
      JS=KS
      IF(JS.GT.NN)GO TO 25
      DO  25  J=JS,NN
      ITA(KN,J)=-1
      IF(BASE(KCOUNT).NE.CODE(J)) GO TO 25
      KS=J+1
      ITA(KN,J)=1
      GO TO 21
25    CONTINUE
      GO TO 5
50    IF(KN.EQ.NB*NTB) GO TO 55
      NERROR=1
      WRITE(6,901)NERROR
      STOP
55    TOT=TOT**2/DFLOAT(NB*NR*NTB)
      IF(FLAG1.EQ.0.0)GO TO 56
      XAQ=9.0D0
      GO TO 57
56    S2=S2*DFLOAT(NR1)
      S21=DFLOAT(NR1*NTS)*DLOG10(S21/DFLOAT(NTS))
      XMM=2.3026D0*(S21-S2)
      XCC=1.0D0+(1.0D0/DFLOAT(3*NTS1))*(DFLOAT(NTS)
     *          /DFLOAT(NR1)-1.0D0/DFLOAT(NR1*NTS))
      XMC=XMM/XCC
      CS=XMC
      AZ=FLOAT(NTS1)
C           THIS PROGRAM USES THE IMSL SUBROUTINE
C           'MDCH' TO CALCULATE THE PROBABALITY ASSOCIATED
C           WITH THE CHI-SQUARE STATISTIC 'M/C'
      CALL MDCH(CS,AZ,AQ,IER)
      XAQ=1.0-AQ
      SMM=SMAX/SMIN
57    YSQ=0.0D0
      DO  80  K=1,NTB
      DO  70  J=1,NB
      Y=0.0D0
      DO  60  I=1,NR
      Y=Y+XBT(J,K,I)
60    CONTINUE
      YSQ=YSQ+Y**2
70    CONTINUE
80    CONTINUE
      ZPURE=TSQ-YSQ/DFLOAT(NR)
      DO  100  K=1,NR
      DO  100  I=1,NB
      X=0.0D0
      DO  90  J=1,NTB
      X=X+XBT(I,J,K)
90    CONTINUE
      XBT(I,1,K)=X
100   CONTINUE
      XB=0.0D0
      X=0.0D0
      DO  120  I=1,NB
      Y=0.0D0
      DO  110  J=1,NR
      X=X+(XBT(I,1,J))**2
      Y=Y+XBT(I,1,J)
110   CONTINUE
      XB=XB+Y**2
120   CONTINUE
      SSWBR=TSQ-X/DFLOAT(NTB)
      SSBBR=X/DFLOAT(NTB)-TOT
      SSB=XB/DFLOAT(NR*NTB)-TOT
      X=0.0D0
      DO  140  I=1,NR
      Y=0.0D0
      DO  130  J=1,NB
      Y=Y+XBT(J,1,I)
130   CONTINUE
      X=X+Y**2
140   CONTINUE
```

```
      SSREP=X/DFLOAT(NTB*NB)-TOT
      SSTOT=TSQ-TOT
      SSRB=SSBBR-SSREP-SSB
      SSRW=ZPURE-SSRB-SSREP
      SSTRT=SSWBR-SSRW
      XBT(1,1,1)=0.0D0
      TS=TSQ
      ZADJ=ZPURE
      TSQ=SSTRT
      ZPURE=0.0D0
      CALL PRINT1(SSBBR,SSREP,SSB,SSRB,SSWBR,SSTRT,
     *SSRW,TS,RMS,ZDFD,TOT,NB,NR,NTB,NN,NP)
      CALL CALC(XBT,TTOT,SMM,XMC,XAQ,RMS,ZDFD,TOT,TSQ,
     *ZPURE,ZTRAST,TS,ZADJ,DUMMY,BASE,FLAG1,ALPHA,NODC,
     *NN,NP,NAS,NB,NR,NTS,NTB,IOPT,KN,KX,KCOUNT,FLAG,INDEX,
     *IDENT,IALIAS)
      RETURN
      END

      SUBROUTINE PRINT1(XA,XB,XC,XD,XE,XF,XG,XH,RMS,ZDFD,
     *TOT,NB,NR,NTB,NN,NP)
      IMPLICIT REAL*8(Q-Z)
100   FORMAT('1'//////////)
101   FORMAT(' ',T40,'GENERALIZED ANOVA ',/18X,58('-'),
     */1X,T27,'SOURCE',T49,'SS',T61,'DF',T71,'MS',
     */18X,58('-'),//1X,T20,'MEAN',T42,F12.3,T52,'1',
     *//1X,T20,'BETWEEN BLOCKS & REPS',
     *T42,F12.3,T57,I6,//1X,T24,'REPLICATIONS',T42,F12.3,
     *T57,I6,//1X,T24,'BLOCKS',T42,F12.3,
     *T57,I6,//1X,T24,'RESIDUAL(BETWEEN)',T42,F12.3,T57,I6,
     *T66,F10.3,///1X,T20,'WITHIN BLOCKS & REPS',T42,F12.3,
     *T57,I6,//1X,T24,'TREATMENTS',T42,F12.3,T57,I6,//1X,
     *T24,'RESIDUAL (WITHIN)',T42,F12.3,T57,I6,T66,F10.3,
     *//18X,58('-'),/1X,T20,'TOTAL',T42,F12.3,T57,
     *I6,/18X,58('-'))
      N1=NB*NR-1
      N2=NR-1
      N3=NB-1
      N4=N2*N3
      N5=NB*NR*(NTB-1)
      N6=IFIX(2.**(NN-NP))-NB
      N7=NB*(NTB-1)*(NR-1)
      N8=NB*NR*NTB
      ZDFD=DFLOAT(N7)
      RMS=XG/DFLOAT(N7)
      Y=0.0D0
      IF(N4.NE.0)Y=XD/DFLOAT(N4)
      WRITE(6,100)
      WRITE(6,101)TOT,XA,N1,XB,N2,XC,N3,XD,N4,Y,XE,N5,XF,N6,
     *XG,N7,RMS,XH,N8
      RETURN
      END

      SUBROUTINE CALC(XBT,TTOT,SMM,XMC,XAQ,RMS,ZDFD,TOT,TSQ,
     *ZPURE,ZTRAST,TS,ZADJ,DUMMY,BASE,FLAG1,ALPHA,NODC,NN,
     *NP,NAS,NB,NR,NTS,NTB,IOPT,KN,KX,KCOUNT,FLAG,INDEX,
     *IDENT,IALIAS,ITA)
      IMPLICIT REAL*8(Q-Z)
      DIMENSION TTOT(NTS,3),XBT(NB,NTB,NR),BASE(12),
     *CODE(14),DUMMY(NTS,4),ADUM(12)
      INTEGER*2 INDEX(12),IDENT(4), ITA(NTS,NN),
     *IALIAS(NAS,NN)
      DATA CODE/'A','B','C','D','E','F','G','H','J','K','L',
     *                                 'M',' ','*'/
      DATA AZERO/'0'/
901   FORMAT(////1X,10X,'ERROR =  ',I2,4X,15A1)
900   FORMAT(15A1)
902   FORMAT(1X,T16,67('-'),/1X,T18,
     '**     INDICATES THAT P(X.GT.F) IS LESS THAN .05',/1X,
     *T18,'****  INDICATES THAT P(X.GT.F) IS LESS THAN .01')
5     KX=KX+1
      READ(5,900)(ADUM(I),I=1,NN)
```

```
      IF(ADUM(1).EQ.AZERO)GO TO 19
      IF(KX.GT.NAS)GO TO 10
      KS=1
      KCOUNT=0
6     KCOUNT=KCOUNT+1
      JS=KS
      IF(JS.GT.NN)GO TO 9
      DO 9 I=JS,NN
      IALIAS(KX,I)=-1
      IF(ADUM(KCOUNT).NE.CODE(I))GO TO 9
      IALIAS(KX,I)=1
      KS=I+1
      GO TO 6
9     CONTINUE
      GO TO 5
10    NZY=2
      WRITE(6,901)NZY
      STOP
19    KX=0
20    READ(5,900)(BASE(IJK),IJK=1,NN)
      IF(BASE(1).EQ.AZERO)GO TO 230
      KS=1
      KCOUNT=0
25    KCOUNT=KCOUNT+1
      JS=KS
      IF(JS.GT.NN)GO TO 30
      DO 30 J=JS,NN
      INDEX(J)=-1
      IF(BASE(KCOUNT).NE.CODE(J))GO TO 30
      IDENT(KCOUNT)=J
      KS=J+1
      GO TO 25
30    CONTINUE
      IF(KCOUNT.GT.4)GO TO 36
      DO 35 J=KCOUNT,4
35    IDENT(J)=13
36    ZTRAST=0.0D0
      Z=0.0D0
      KCOUNT=KCOUNT-1
      DO 37 J=1,KCOUNT
37    INDEX(IDENT(J))=1
      DO 38 J=1,NN
      BASE(J)=INDEX(J)
38    CONTINUE
      NZXY=NB*NTB
      DO 100 I=1,NZXY
      Y=1.0D0
      DO 40 J=1,KCOUNT
      Y=Y*ITA(I,IDENT(J))
40    CONTINUE
      ZTRAST=ZTRAST+Y*TTOT(I,1)
      Z=Z+Y
100   CONTINUE
      IF(DABS(Z).LT.1.0D0)GO TO 110
      NERROR=3
      WRITE(6,901)NERROR,(CODE(IDENT(I)),I=1,KCOUNT)
      STOP
110   CALL PRINT2(XBT,TTOT,RMS,ZDFD,TOT,TSQ,ZPURE,ZTRAST,
     *TS,ZADJ,DUMMY,BASE,FLAG1,ALPHA,NODC,NN,NP,NAS,NB,NR,
     *NTS,NTB,IOPT,KN,KX,KCOUNT,FLAG,INDEX,IDENT,IALIAS,ITA)
      GO TO 20
230   SSREG=XBT(1,1,1)+TOT
      IF(IOPT.NE.2)WRITE(6,902)
      IF(IOPT.GT.1)CALL PRINT3(TTOT,RMS,ZDFD,TOT,TSQ,
     *ZPURE,ZADJ,SSREG,TS,ZTRAST,SMM,XMC,XAQ,DUMMY,BASE,
     *NAS,KX,ALPHA,NODC,NN,NTS,NP,NR,NB,NTB,IALIAS,
     *INDEX,ITS)
      RETURN
      END
```

```
      SUBROUTINE PRINT2(XBT,TTOT,RMS,ZDFD,TOT,TSQ,ZPURE,
     *ZTRAST,TS,ZADJ,DUMMY,BASE,FLAG1,ALPHA,NODC,NN,NP,NAS,
     *NB,NR,NTS,NTB,IOPT,KN,KX,KCOUNT,FLAG,INDEX,IDENT,
     *IALIAS,ITA)
      IMPLICIT REAL*8(Q-Z)
      DIMENSION TTOT(NTS,3),XDUM(12),XBT(NB,NTB,NR),
     *BASE(12),CODE(14),ANONE(4),DUMMY(NTS,4)
      INTEGER*2 INDEX(12),IDENT(4), ITA(NTS,NN),
     *IALIAS(NAS,NN)
      DATA CODE/'A','B','C','D','E','F','G','H','J','K','L',
     *                                     'M',' ','*'/
      DATA ANONE/'N','O','N','E'/
      DATA PROB/'    '/,PROB1/'**  '/,PROB2/'****'/
900   FORMAT('1'//////)
901   FORMAT(1X,T16,67('-'),/1X,T25,'2/3 FI',T52,'MEAN',
     *T63,'F',T72,'PROB',/1X,T17,'SOURCE ALIASE  DF EFFECT',
     *5X,'SQUARE  STATISTIC   (X.GT.F)',/1X,T16,67('-'))
903   FORMAT(/1X,T42,'TREATMENT ANOVA')
904   FORMAT(1X,T19,4A1,T34,'1',T36,2(F10.3,1X),2F9.3,2X,A4)
905   FORMAT(1X,T27,6A1)
906   FORMAT(////1X,T10,'ERROR =  ',I2,4X,15A1)
907   FORMAT(1X,T16,67('-'),/1X,T18,
     *'**   INDICATES THAT P(X.GT.F) IS LESS THAN .05',/1X,
     *T18,'****  INDICATES THAT P(X.GT.F) IS LESS THAN .01')
      IF(IOPT.EQ.2)GO TO 10
      IF(FLAG.LT.65.0) GO TO 10
      IF(FLAG.NE.9999.0) WRITE(6,907)
      WRITE(6,900)
      IF(FLAG.EQ.9999.0) WRITE(6,903)
      WRITE(6,901)
      FLAG=11.0
10    ZFCT=ZTRAST/(DFLOAT(NR)*2.**(NN-NP-1))
      XMS=ZTRAST**2/(DFLOAT(NR)*2.**(NN-NP))
      ZPURE=ZPURE+XMS
      IF(ZPURE.GT.TSQ+.001D0) GO TO 500
      FS=XMS/RMS
      DFD=SNGL(ZDFD)
C                        THIS PROGRAM USES SUBROUTINE 'MDFDRE'
C                        FROM THE IMSL LIBRARY TO CALCULATE
C                        THE TAIL AREA PROBABILITY ASSOCIATED
C                        WITH THE CALCULATED F-STATISTIC
      CALL MDFDRE(FS,1.,DFD,PTEST,IER)
      PTEST=1.0-PTEST
      IF(IOPT.LT.2)GO TO 35
      IF(PTEST.GT.ALPHA)GO TO 35
      TTOT(KX+1,3)=XMS
      TTOT(KX+1,2)=ZFCT/2.0D0
      DO 30 J=1,4
      DUMMY(KX+1,J)=IDENT(J)
30    CONTINUE
      KX=KX+1
      XBT(1,1,1)=XBT(1,1,1)+XMS
35    AYX=PROB
      IF(PTEST.LE..05) AYX=PROB1
      IF(PTEST.LE..01) AYX=PROB2
50    IF(IOPT.EQ.2) RETURN
      WRITE(6,904) (CODE(IDENT(I)),I=1,4),ZFCT,XMS,FS,
     *PTEST,AYX
      FLAG1=0.0
      FLAG=FLAG+1.0
      IF(NODC.EQ.1) RETURN
      IF(IALIAS(1,1).EQ.0) RETURN
      DO 100 I=1,NAS
      NK=1
      DO 80 J=1,NN
      IF(BASE(J)*IALIAS(I,J).GT.0.0)GO TO 80
      INDEX(NK)=J
      NK=NK+1
80    CONTINUE
      NK=NK-1
      IF(NK.GT.3.OR.NK.LE.0)GO TO 100
      WRITE(6,905) (CODE(INDEX(NI)),NI=1,NK)
```

```
      FLAG1=1.0
      FLAG=FLAG+1.0
100   CONTINUE
      IF(FLAG1.GT.0.0)RETURN
      WRITE(6,905)ANONE
      FLAG=FLAG+1.0
      RETURN
500   NERROR=4
      WRITE(6,906)NERROR
      STOP
      END

      SUBROUTINE PRINT3(TTOT,RMS,ZDFD,TOT,TSQ,ZPURE,
     *ZADJ,SSRG,TS,ZTRAST,SMM,XMC,XAQ,DUMMY,BASE,NAS,KX,
     *ALPHA,NODC,NN,NTS,NP,NR,NB,NTB,IALIAS,ITA)
      IMPLICIT REAL*8(Q-Z)
      DIMENSION TTOT(NTS,3),CODE(14),BASE(12),DUMMY(NTS,4)
      INTEGER*2 INDEX(12),IDENT(4), ITA(NTS,NN),
     *IALIAS(NAS,NN)
      DATA CODE/'A','B','C','D','E','F','G','H','J','K','L',
     *                'M',' ','*'/
      DATA PROB/'    '/,PROB1/'**  '/,PROB2/'****'/
      DATA PARL/'('/,PARR/')'/,PARM/'1'/
900   FORMAT('1'//1X,T39,'GENERAL ANOVA FOR SELECTED MODEL',
     */1X,T20,68('-'),/1X,T44,'SUM OF',T62,'MEAN',T73,'F',
     *T81,'PROB',/1X,T23,'SOURCE',T44,'SQUARES',T54,'DF',
     *T61,'SQUARES STATISTIC (X.GT.F)',/1X,T20,68('-'))
901   FORMAT(/1X,T21,'MEAN',T40,F11.3,T55,'1',T57,F10.3,
     *//1X,T21,'REGRESSION(TERMS)',T40,F11.3,T52,I4,T57,
     *2F10.3,F9.4,1X,A4,/1X,T21,'RESIDUAL',T40,F11.3,T52,I4)
902   FORMAT(/1X,T24,'LACK OF FIT',T40,F11.3,T52,I4,T57,
     *2F10.3,F9.4,1X,A4)
903   FORMAT(/1X,T24,'SOURCES(BETWEEN)',T40,F11.3,T52,I4)
904   FORMAT(/1X,T24,'ERROR(ADJUSTED)',T40,F11.3,T52,I4,
     *T57,F10.3)
905   FORMAT(/1X,T20,68('-'),/1X,T21,'TOTAL',T37,F14.3,
     *T52,I4,/1X,T20,68('-'))
906   FORMAT('1'///1X,T36,'STATISTICS FOR SELECTED MODEL',
     */1X,T18,65('-'),/1X,T31,'REGRESSION',
     *T49,'SUM  OF',T67,'F',T76,'PROB',/1X,T19,'VARIABLE',
     *T31,'COEFFICIENT',T49,'SQUARES   DF',T63,
     *'STATISTIC  (X.GT.F)',/1X,T18,65('-'),//1X,T21,
     *'MEAN',T28,F14.5,T44,F12.3,T60,'1')
907   FORMAT(/1X,T21,4A1,T28,F14.5,T44,F12.3,T60,'1',F11.3,
     *F10.4,1X,A4)
908   FORMAT(/1X,T18,65('-'),/1X,T19,'TOTAL REGRESSION',T44,
     *F12.3,T57,I4,/1X,T18,65('-'))
909   FORMAT(1X,T21,'**  INDICATES SIGNIFICANCE AT .025')
911   FORMAT(////1X,T20,
     *'PERCENT VARIABILITY THAT CAN BE EXPLAINED BY
     *REGRESSION:',F10.4,'',///1X,T20,
     *'PERCENT VARIABILITY EXPLAINED BY THE SELECTED
     *MODEL:',F10.4,'',///1X,T20,
     *'SAMPLE MULTIPLE CORRELATION COEFFICIENT:',F6.4)
912   FORMAT(1X,T21,'**     INDICATES SIGNIFICANCE AT .05',
     */1X,T21,'****  INDICATES SIGNIFICANCE AT .01')
913   FORMAT(//1X,T20,'STANDARD DEVIATION OF RESIDUALS: ',
     *F10.4,///1X,T20,'MEAN RESIDUAL MAGNITUDE: ',F10.4,
     *///1X,T20,'MAXIMUM DEVIATION BETWEEN PREDICTED &
     *OBSERVED VALUES:',F10.4,///1X,T20,
     *'PERCENTAGE OF OBSERVED VALUES FALLING ',/1X,T20,
     *'WITHIN 1(ONE)STANDARD DEVIATION OF REGRESSION LINE:',
     *F8.2,'%',///1X,T20,'PERCENTAGE OF OBSERVED VALUES FALL
     *ING',/1X,T20,'WITHIN 2(TWO) STANDARD DEVIATIONS OF
     *REGRESSION LINE:',F8.2,' %',///1X,T20,
     *'NUMBER OF RESIDUALS WHOSE MAGNITUDE IS GREATER',
     */1X,T20,'THAN 2(TWO) STANDARD DEVIATIONS: ',I5)
914   FORMAT('1')
915   FORMAT('1'//////1X,T18,59('-'),/1X,T39,'MEAN OF',/1X,
     *T20,'TREATMENT',T35,'OBSERVED VALUES',T52,'PREDICTED
     *VALUE',T70,'RESIDUAL',/1X,T18,59('-')/)
916   FORMAT(1X,T18,12A1,T35,F12.4,T52,F12.4,T67,F8.4,3X,A4)
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```
917   FORMAT(/1X,T18,59('-'),/1X,T20,
     *'**  INDICATES RESIDUAL MAGNITUDE EXCEEDS',/1X,T26,
     *'2 (TWO) STANDARD DEVIATIONS')
919   FORMAT(////1X,T25,'RMS =  ',F25.16,15X,'D.F. =  ',
     *F25.16)
      IX=KX+1
      SRA=SSRG-TOT
      TSX=TS-TOT
      XYZ=DSQRT(TOT/DFLOAT(NB*NR*NTB))
      WRITE(6,906) XYZ,TOT
      IF(KX.LT.1)GO TO 100
      DO 100 J=1,KX
      AY=PROB
      FS=TTOT(J,3)/RMS
      DFD=SNGL(ZDFD)
      CALL MDFDRE(FS,1.0,DFD,PTEST,IER)
      PTEST=1.0-PTEST
      IF(PTEST.LE..025) AY=PROB1
      DO 33 KK=1,4
33    INDEX(KK)=IFIX(DUMMY(J,KK))
      WRITE(6,907) (CODE(INDEX(K)),K=1,4),
     *(TTOT(J,KKZ),KKZ=2,3),FS,PTEST,AY
100   CONTINUE
      WRITE(6,908) SSRG,IX
      WRITE(6,909)
      WRITE(6,900)
      AY=PROB
      XMS=0.0D0
      FS=0.0
      IF(KX.LT.1)GO TO 41
      X=DFLOAT(KX)
      XMS=SRA/X
      FS=XMS/RMS
      CALL MDFDRE(FS,X,DFD,PTEST,IER)
      PTEST=1.0-PTEST
      IF(PTEST.LE..05) AY=PROB1
      IF(PTEST.LE..01) AY=PROB2
41    Z=TS-SSRG
      NT=IFIX(2.**(NN-NP)*FLOAT(NR))
      IZ=NT-IX
      WRITE(6,901)TOT,TOT,SRA,KX,XMS,FS,PTEST,AY,Z,IZ
      IXX=IFIX(2.**(NN-NP))-(NB+KX)
      SSLOF=TSQ-SSRG+TOT
      IF(IXX.LE.0)GO TO 30
      X=DFLOAT(IXX)
      XMS=SSLOF/X
      FS=XMS/RMS
      CALL MDFDRE(FS,X,DFD,PTEST,IER)
      PTEST=1.0-PTEST
      AY=PROB
      IF(PTEST.LE..05) AY=PROB1
      IF(PTEST.LE..01) AY=PROB2
      WRITE(6,902) SSLOF,IXX,XMS,FS,PTEST,AY
30    X=Z-SSLOF-RMS*ZDFD
      IXY=NB*NR-1
      IF(IXY.GT.0) WRITE(6,903) X,IXY
      X=RMS*ZDFD
      N=ZDFD
      WRITE(6,904) X,N,RMS
      WRITE(6,905) TS,NT
      WRITE(6,912)
      XDSQ=0.0D0
      ZTEST=0.0D0
      XDAV=0.0D0
      YTEST=0.0D0
      STD=0.0D0
      XDMAX=-100.0D0
      DO 150 I=1,NTS
      X=XYZ
      IF(KX.LT.1)GO TO 120
      DO 120 J=1,KX
      Z=1.0D0
```

```
      N=IFIX(DUMMY(J,1))
      Z=Z*ITA(I,N)
      DO 110 K=2,4
      N=IFIX(DUMMY(J,K))
      IF(N.GT.NN)GO TO 111
      Z=Z*ITA(I,N)
110   CONTINUE
111   X=X+Z*TTOT(J,2)
120   CONTINUE
      XM=TTOT(I,1)/DFLOAT(NR)
      XY=XM-X
      TTOT(I,3)=XY
      XDSQ=XDSQ+XY*XY
      STD=STD+XY
      XDAV=XDAV+DABS(XY)
150   CONTINUE
      X=DFLOAT(NTS)
      ZMEAN=STD/X
      XMEAN=XDAV/X
      STD=DSQRT((XDSQ-X*ZMEAN**2)/(X-1.0D0))
      N1=0
      N2=0
      DO 200 I=1,NTS
      IF(DABS(TTOT(I,3)).GT.XDMAX)XDMAX=DABS(TTOT(I,3))
      IF(DABS(TTOT(I,3)).LE.2.0D0*STD)N2=N2+1
      IF(DABS(TTOT(I,3)).LE.STD)N1=N1+1
      TTOT(I,1)=TTOT(I,1)/DFLOAT(NR)
      TTOT(I,2)=TTOT(I,1)-TTOT(I,3)
200   CONTINUE
      NX=NTS-N2
      Z=100.0D0*DFLOAT(N1)/DFLOAT(NTS)
      ZX=100.0D0*DFLOAT(N2)/DFLOAT(NTS)
      XA=100.0D0*TSQ/TSX
      XB=100.0D0*SRA/TSX
      XC=DSQRT(SRA/TSX)
      WRITE(6,911)XA,XB,XC
      WRITE(6,913)STD,XMEAN,XDMAX,Z,ZX,NX
      CALL KSTEST(TTOT,XMC,SMM,XAQ,STD,ZMEAN,DUMMY,NTS,NR)
      WRITE(6,915)
      KCOUNT=11
      DO 300 I=1,NTS
      II=IFIX(DUMMY(I,3))
      K=0
      DO 240 J=1,NN
      IF(ITA(II,J).LT.0)GO TO 240
      K=K+1
      INDEX(K)=J
240   CONTINUE
      IF(K.EQ.12)GO TO 260
      K=K+1
      DO 250 J=K,12
250   INDEX(J)=13
260   AY=PROB
      IF(DABS(TTOT(I,3)).GT.2.0D0*STD)AY=PROB1
      IF(KCOUNT.LE.65)GO TO 270
      WRITE(6,917)
      WRITE(6,915)
      KCOUNT=11
270   IF(DUMMY(I,3).EQ.1.0)GO TO 290
      WRITE(6,916)(CODE(INDEX(KK)),KK=1,12),
     *(TTOT(I,KK),KK=1,3),AY
      KCOUNT=KCOUNT+1
      GO TO 300
290   WRITE(6,916)PARL,PARM,PARR,(CODE(INDEX(KK)),KK=4,12),
     *(TTOT(I,KK),KK=1,3),AY
      KCOUNT=KCOUNT+1
300   CONTINUE
      WRITE(6,917)
      WRITE(6,914)
      WRITE(6,919)RMS,ZDFD
      RETURN
      END
```

```
      SUBROUTINE KSTEST(TTOT,XMC,SMM,XAQ,SIG,ZMEAN,DUMMY,
     *NTS,NR)
      IMPLICIT REAL*8(Q-Z)
      DIMENSION TTOT(NTS,3),DUMMY(NTS,4)
901   FORMAT(////1X,T21,'KS TEST FOR NORMALITY ASSUMPTION',
     */1X,T21,32('-'),//1X,T25,'KS STATISTIC (DMAX) : ',
     *F9.6,/1X,T25,'PROB( X .GT. KS) : ',F9.6)
902   FORMAT('1',//////////1X,T22,44('*'),/1X,T22,
     *'* STATISTICS FOR TESTING ANOVA ASSUMPTIONS *',
     */1X,T22,44('*'))
903   FORMAT(///1X,T21,
     *'BARTLETT TEST FOR HOMOGENEITY OF CELL VARIANCES',/1X,
     *T21,47('-'),/1X,T25,'M / C    (CHI SQUARE) : ',F12.4,
     *//1X,T25,'DEGREES OF FREEDOM : ',I10,
     *//1X,T25,'PROB( X .GT. M/C ) : ',F10.6,///1X,T21,
     *'F MAX RATIO',/1X,T21,11('-'),/1X,T25,
     *'S**2(MAX) / S**2(MIN) : ',F12.4,//1X,T25,
     *'G (NUMBER OF CELLS) : ',I10,//1X,T25,
     *'DEGREES OF FREEDOM FOR EACH S : ',I10)
      N1=NTS-1
      NR1=NR-1
      DO 10 I=1,NTS
10    DUMMY(I,3)=FLOAT(I)
      DO 20 I=1,N1
      I1=1+I
      DO 20 J=I1,NTS
      IF(TTOT(J,3).GE.TTOT(I,3))GO TO 20
      TSAVE3=TTOT(I,3)
      TSAVE1=TTOT(I,1)
      TSAVE2=TTOT(I,2)
      DSAVE=DUMMY(I,3)
      TTOT(I,3)=TTOT(J,3)
      TTOT(I,1)=TTOT(J,1)
      TTOT(I,2)=TTOT(J,2)
      DUMMY(I,3)=DUMMY(J,3)
      TTOT(J,2)=TSAVE2
      TTOT(J,1)=TSAVE1
      TTOT(J,3)=TSAVE3
      DUMMY(J,3)=DSAVE
20    CONTINUE
      DO 50 I=1,NTS
      XXZ=(TTOT(I,3)-ZMEAN)/SIG
      DUMMY(I,1)=.5D0*DERFC(-.7071068D0*XXZ)
      DUMMY(I,2)=FLOAT(I)/FLOAT(NTS)
50    CONTINUE
      DMAX=-999.0
      DO 100 I=1,NTS
      AZ=ABS(DUMMY(I,1)-DUMMY(I,2))
      IF(AZ.GT.DMAX)DMAX=AZ
      IF(I.EQ.NTS)GO TO 100
      AZ=ABS(DUMMY(I+1,1)-DUMMY(I,2))
      IF(AZ.GT.DMAX)DMAX=AZ
100   CONTINUE
      DKS=DMAX*SQRT(FLOAT(NTS))
C                THIS SUBROUTINE USES THE IMSL SUBROUTINE
C                'MDSMR' TO CALCULATE THE PROBABILITY
C                ASSOCIATED WITH THE KS STATISTIC.
      CALL MDSMR(DKS,P1,P2)
      PROB=1.0-P2
      WRITE(6,902)
      IF(XAQ.LE.1.0D0)WRITE(6,903)XMC,N1,XAQ,SMM,NTS,NR1
      WRITE(6,901)DMAX,NTS,PROB
      RETURN
      END
```

```
C ***************************************************************
C *  PROGRAM TO ANALYZE SIGNIFICANT 2-FACTOR AND 3-FACTOR
C *  INTERACTIONS IN A 2**(N-P) FACTORIAL DESIGN
C ***************************************************************
C
C
C THIS PROGRAM IS DESIGNED TO ANALYZE SIGNIFICANT 2-FACTOR
C AND 3-FACTOR INTERACTIONS IN ANY 2**(N-P) FACTORIAL
C DESIGN.  THIS INCLUDES THE FULL FACTORIAL WITH OR
C WITHOUT BLOCK CONFOUNDING, AND THE FRACTIONAL FACTORIAL
C WITH OR WITHOUT BLOCK CONFOUNDING.  AS SUCH, THE PROGRAM
C WILL CALCULATE THE ANOVA FOR SIMPLE MAIN EFFECTS IN
C 2-FACTOR INTERACTIONS; AND SIMPLE SIMPLE MAIN EFFECTS
C AND SIMPLE INTERACTION EFFECTS IN 3-FACTOR INTERACTIONS.
C
C
C THIS PROGRAM IS DESIGNED TO BE USED IN CONJUNCTION WITH
C 'ZNOVA',AND AS SUCH DATA ENTRY IS IDENTICAL WITH THAT OF
C 'ZNOVA'.  FACTORS/TREATMENTS ARE DESIGNATED BY THE
C LETTERS -- A,B,C,D,E,F,G,H,J,K,L,M.
C
C
C THIS PROGRAM REQUIRES THAT THE RESIDUAL MEAN SQUARE AND
C THE DEGREES OF FREEDOM FOR THE RESIDUAL MEAN SQUARE BE
C DESIGNATED AS INPUT IN THE MAIN PROGRAM, AND AS SUCH,
C THE ONLY RESTRICTIONS THAT APPLY IN THE USE OF THIS
C PROGRAM ARE THE FOLLOWING:
C
C                             1.  'N' IS LESS THAN 13
C                             2.  ALL FACTORS ARE FIXED
C                             3.  NO MISSING OBSERVATIONS
C
C
C PROGRAM USAGE:
C
C    CALL ZEFCTS(TA,DUMMY,TTOT,BASE,ALPHA,DFD,RMS,NN,NR,NTS)
C
C
C WHERE THE ABOVE ARGUMENTS ARE DEFINED AS FOLLOWS:
C
C ALPHA -- REAL VARIABLE, EQUALS DESIRED LEVEL OF
C          SIGNIFICANCE FOR F-TEST.
C RMS -- REAL VARIABLE, EQUALS RESIDUAL MEAN SQUARE.
C DFD -- REAL VARIABLE, EQUALS DEGREES OF FREEDOM FOR
C          THE RESIDUAL MEAN SQUARE.
C NN --INTEGER VARIABLE, EQUALS NUMBER OF FACTORS/TREATMENTS
C          CORRESPONDS TO 'N' IN 2**(N-P).
C NR --INTEGER VARIABLE,EQUALS NUMBER OF REPLICATIONS.
C NTS --INTEGER VARIABLE, EQUALS NUMBER OF TREATMENT
C          COMBINATIONS PER REPLICATION. I.E. NTS = 2**(N-P)
C
C TA --REAL WORK ARRAY DIMENSIONED AS TA(NTS,NN).
C TTOT --REAL WORK ARRAY DIMENSIONED AS TTOT(NTS).
C DUMMY --REAL WORK ARRAY DIMENSIONED AS DUMMY(NR).
C BASE --REAL WORK ARRAY DIMENSIONED AS BASE(NN).
C
C
C ERROR CODES ARE AS FOLLOWS:
C
C ERROR = 1   INDICATES THAT THE NUMBER OF TREATMENT
C             COMBINATIONS READ (DATA GROUP I) DOES NOT EQUAL
C             NTS.
C
C ERROR = 2   **** INDICATES THAT AN IMPROPER CONTRAST WAS
C             ENCOUNTERED IN COMPUTING THE SUM OF SQUARES FOR
C             FACTORIAL EFFECT ****. (DATA GROUP II)  THIS IS
C             MOST PROBABLY DUE TO IMPROPER TYPING OF
C             TREATMENT CODES IN DATA GROUP I.
```

```
C DATA INPUT IS ACCOMPLISHED IN TWO GROUPS AS FOLLOWS:
C
C NOTE THAT IN THE DATA DECK, EACH OF THESE DATA GROUPS
C IS FOLLOWED BY THE FOLLOWING DATA CARD:
C
C     CC  12345678901234567890123456789012345678901234567890
C         00000000000000000000000000000000000000000000000000
C                (ZERO'S)
C
C
C
C 1.  DATA GROUP I LISTS THE TREATMENT CODE ON CARD 1, AND
C     OBSERVATIONS ON CARD 2.
C
C    FORMATS USED ARE:
C
C         FOR CARD 1 --**** FORMAT(20X,12A1)
C
C         FOR CARD 2 --**** FORMAT(15F10.4)
C
C EXAMPLE WHERE TREATMENT COMBINATION IS 'ACDEFLM' AND
C 3 OBSERVATIONS ARE:  1102.36, 1205.1, 1261.56.
C
C           CC  1234567890123456789012345678901234567890
C       CARD 1                      ACDEFLM
C       CARD 2  1102.36   1205.1    1261.56
C
C
C 2.  DATA GROUP II LISTS ANY SIGNIFICANT 2-FACTOR AND
C 3-FACTOR INTERACTIONS WHICH YOU DESIRE TO FURTHER ANALYZE.
C
C    FORMAT USED IS **** FORMAT(3A1)
C
C EXAMPLE WHERE IT IS DESIRED TO FURTHER ANALYZE THE
C 3-FACTOR INTERACTION  'GJM'.
C
C    CC 12345678901234567890123456789012345678901234567890
C       GJM
C
C
C TO DEMONSTRATE DATA INPUT THE FOLLOWING EXAMPLE IS
C PRESENTED:
C
C
C EXAMPLE:   2**2 FULL FACTORIAL WITH 3 REPLICATIONS
C              (3 OBSERVATIONS PER CELL), WHERE THE RESIDUAL
C              MEAN SQUARE WAS PREVIOUSLY CALCULATED TO BE
C              4.58 AND DEGREES OF FREEDOM FOR THE RESIDUAL
C              MEAN SQUARE IS 8.  IT IS DESIRED TO FURTHER
C              ANALYZE THE 'AB' INTERACTION.
C
C OBSERVATIONS:
C    TREATMENT COMBINATIONS     REP I     REP II     REP III
C           (1)                  0.0       2.0        1.0
C            A                   4.0       6.0        2.0
C            B                  -1.0      -3.0        1.0
C           AB                  -1.0      -3.0       -7.0
C
C
C MAIN PROGRAM DECK WOULD BE AS FOLLOWS:
C
C    DIMENSION TA(4,2),DUMMY(3),TTOT(4),BASE(2)
C    ALPHA=.05
C    RMS=4.58
C    DFD=8.0
C    NN=2
C    NR=3
C    NTS=4
C    CALL ZEFCTS(TA,DUMMY,TTOT,BASE,ALPHA,DFD,RMS,NN,NR,NTS)
C    STOP
C    END
```

```
C DATA DECK WOULD BE AS FOLLOWS:
C
C                         CC 1234567890123456789012345678901
C                            -------------------------------
C                           /0000000000000000000000000000000
C                          ---------------------------------
C                         /AB
C                        -----------------------------------
C                       /00000000000000000000000000000000000
C                      -------------------------------------
C                     /-1.0      -3.0      -7.0
C                    ---------------------------------------
C                   /                    AB
C                  .........................................
C                 ..........................................
C                -------------------------------------------
C               /0.0       2.0       1.0
C              ---------------------------------------------
C   CARD 1    /                    (1)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C *  DESIGNED AND PROGRAMMED BY  BROUSSARD,G     NPS  1979
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


      DIMENSION TA(128,11),TTOT(128),BASE(11),DUMMY(8)
      NN=11
      NR=8
      NTS=128
      DFD=840.0
      RMS=.03790987
      ALPHA=.05
      CALL ZEFCTS(TA,DUMMY,TTOT,BASE,ALPHA,DFD,
     *RMS,NN,NR,NTS)
      STOP
      END

      SUBROUTINE ZEFCTS(TA,DUMMY,TTOT,BASE,ALPHA,DFD,RMS,
     *NN,NR,NTS)
      DIMENSION TA(NTS,NN),DUMMY(NR),TTOT(NTS),BASE(NN),
     *CASE(3),ID(3),IDENT(2),CODE(14)
      DATA CODE/'A','B','C','D','E','F','G','H','J','K','L',
     *                      'M',' ','*'/
      DATA KN/0/,ZERO/'0'/,TBAR/0.0/
800   FORMAT(20X,15A1)
801   FORMAT(////1X,10X,'ERROR = ',I2,3X,15A1)
802   FORMAT(15F10.4)
803   FORMAT(15A1)
5     READ(02,800) (BASE(I),I=1,NN)
      IF(BASE(1).EQ.ZERO)GO TO 50
      READ(02,802) (DUMMY(I),I=1,NR)
      KN=KN+1
      X=0.0
      DO 20 J=1,NR
C  TRANSFORMATION CARD GOES HERE  I.E.  DUMMY(J)=F(DUMMY(J))
      DUMMY(J)=ARSIN(SQRT(DUMMY(J)))
      X=X+DUMMY(J)
20    CONTINUE
      TTOT(KN)=X
      TBAR=TBAR+X
      KS=1
      KCOUNT=0
35    KCOUNT=KCOUNT+1
      JS=KS
      IF(JS.GT.NN)GO TO 40
      DO 40 J=JS,NN
      TA(KN,J)=-1.0
      IF(BASE(KCOUNT).NE.CODE(J))GO TO 40
      KS=J+1
```

```
      TA(KN,J)=1.0
      GO TO 35
40    CONTINUE
      GO TO 5
50    TBAR=TBAR/FLOAT(NTS*NR)
      IF(KN.EQ.NTS)GO TO 55
      NERROR=1
      WRITE(6,801)NERROR
      STOP
55    READ(02,803)(CASE(I),I=1,3)
      IF(CASE(1).EQ.ZERO) RETURN
      KEND=0
      KSTART=1
60    JSTART=KSTART
      KEND=KEND+1
      IF(JSTART.GT.3)GO TO 80
      DO 80 I=JSTART,NN
      IF(CASE(KEND).NE.CODE(I))GO TO 80
      ID(KEND)=I
      KSTART=I+1
      GO TO 60
80    CONTINUE
      KEND=KEND-1
      IF(KEND.EQ.2)CALL PRINT1(TA,TTOT,CODE,BASE,CASE,TBAR,
     *ID,IDENT,ALPHA,RMS,DFD,NN,NR,NTS)
      IF(KEND.EQ.3)CALL PRINT2(TA,TTOT,CODE,BASE,CASE,TBAR,
     *ID,IDENT,ALPHA,RMS,DFD,NN,NR,NTS)
      GO TO 55
      END


      SUBROUTINE PRINT1(TA,TTOT,CODE,BASE,CASE,TBAR,ID,
     *IDENT,ALPHA,RMS,DFD,NN,NR,NTS)
      DIMENSION TA(NTS,NN),TTOT(NTS),CODE(14),BASE(NN),
     *CASE(3),ID(3),IDENT(2),CBAR(4)
900   FORMAT('1',////1X,T35,'ANOVA FOR SIMPLE MAIN EFFECTS',
     */1X,T20,59('-'),/1X,T22,'SOURCE',T37,'SS      DF',
     *T49,'EFFECT',T61,'F      P(X.GT.F)',/1X,T20,59('-'))
901   FORMAT(//1X,T21,2A1,T33,F9.3,T45,'1',T46,F9.3,
     *T56,F9.3,F8.3,T75,6A1)
902   FORMAT(//1X,T21,A1,' AT ',A1,'(0)',T33,F9.3,T45,'1',
     *T46,F9.3,T56,F9.3,F8.3,T75,6A1)
903   FORMAT(//1X,T21,A1,' AT ',A1,'(1)',T33,F9.3,T45,'1',
     *T46,F9.3,T56,F9.3,F8.3,T75,6A1)
904   FORMAT(/1X,T20,59('-'),/1X,T21,
     *'**  INDICATES THAT P(X.GT.F) IS LESS THAN ',F5.4,
     *' FOR MAIN',/1X,T21,'AND INTERACTION EFFECTS, AND LESS
     *THAN ',F5.4,'  FOR SIMPLE',/1X,T21,'MAIN EFFECTS.')
905   FORMAT(/10X,'ERROR = ',I2,4X,15A1)
906   FORMAT(/1X,T24,'GRAND MEAN = ',F12.4,//1X,T42,14('*'),
     */1X,T42,'* CELL MEANS *',/1X,T42,14('*'),///1X,T48,A1,
     */1X,T47,'---',T38,'(LOW)',T54,'(HIGH)',/1X,T48,':',
     */1X,T26,'(LOW)',T32,F14.5,T48,':',F14.5,/1X,T48,':',
     */1X,T24,A1,T32,33('-'),/1X,T23,'---',T48,
     *':','(HIGH)',T32,F14.5,T48,':',F14.5,/1X,T48,':')
      A=0.0
      B=0.0
      AB=0.0
      DO 1 I=1,4
1     CBAR(I)=0.0
      BETA=ALPHA/2.0
      CHECK1=0.0
      CHECK2=0.0
      DO 150 I=1,NTS
      A=A+TA(I,ID(1))*TTOT(I)
      B=B+TA(I,ID(2))*TTOT(I)
      AB=AB+TTOT(I)*TA(I,ID(1))*TA(I,ID(2))
      IF(TA(I,ID(2)).GT.0.0)GO TO 30
      IF(TA(I,ID(1)).GT.0.0)GO TO 15
      CBAR(1)=CBAR(1)+TTOT(I)
      GO TO 30
15    CBAR(3)=CBAR(3)+TTOT(I)
```

```
30      IF(TA(I,ID(2)).LT.0.0)GO TO 149
        IF(TA(I,ID(1)).GT.0.0)GO TO 40
        CBAR(2)=CBAR(2)+TTOT(I)
        GO TO 149
40      CBAR(4)=CBAR(4)+TTOT(I)
149     CHECK1=CHECK1+TA(I,ID(1))
        CHECK2=CHECK2+TA(I,ID(2))
150     CONTINUE
        IF(ABS(CHECK1)+ABS(CHECK2).LE..001)GO TO 160
        NERROR=2
        WRITE(6,905)NERROR,(CODE(ID(I)),I=1,2)
        STOP
160     Z=FLOAT(NR)*FLOAT(NTS)
        ZX=Z/2.0
        ZY=Z/4.0
        AATB1=CBAR(4)-CBAR(2)
        AATB0=CBAR(3)-CBAR(1)
        BATA0=CBAR(2)-CBAR(1)
        BATA1=CBAR(4)-CBAR(3)
        DO 170 I=1,4
170     CBAR(I)=CBAR(I)/ZY
        WRITE(6,900)
        XX=A/ZX
        A=A**2/Z
        FS=A/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
        WRITE(6,901)CODE(ID(1)),CODE(13),A,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=AATB0/ZY
        AATB0=AATB0**2/ZX
        FS=AATB0/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,BETA)
        WRITE(6,902)(CODE(ID(I)),I=1,2),AATB0,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=AATB1/ZY
        AATB1=AATB1**2/ZX
        FS=AATB1/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,BETA)
        WRITE(6,903)(CODE(ID(I)),I=1,2),AATB1,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=B/ZX
        B=B**2/Z
        FS=B/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
        WRITE(6,901)CODE(ID(2)),CODE(13),B,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=BATA0/ZY
        BATA0=BATA0**2/ZX
        FS=BATA0/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,BETA)
        WRITE(6,902)CODE(ID(2)),CODE(ID(1)),BATA0,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=BATA1/ZY
        BATA1=BATA1**2/ZX
        FS=BATA1/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,BETA)
        WRITE(6,903)CODE(ID(2)),CODE(ID(1)),BATA1,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        XX=AB/ZX
        AB=AB**2/Z
        FS=AB/RMS
        CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
        WRITE(6,901)CODE(ID(1)),CODE(ID(2)),AB,XX,FS,PTEST,
       *(CODE(IDENT(I)),I=1,2)
        WRITE(6,904)ALPHA,BETA
        WRITE(6,906)TBAR,CODE(ID(2)),CBAR(1),CBAR(2),
       *CODE(ID(1)),CBAR(3),CBAR(4)
        RETURN
        END
```

```
      SUBROUTINE FTEST(IDENT,FS,DFD,PTEST,ALPHA)
C                 THIS SUBROUTINE USES AN IMSL SUBROUTINE
C                 'MDFDRE' TO CALCULATE THE PROBABILITY
C                 THAT THE F-STATISTIC EXCEEDS THE ALPHA
C                 LEVEL DESIGNATED.
      DIMENSION IDENT(2)
      CALL MDFDRE(FS,1.0,DFD,PTEST,IER)
      PTEST=1.0-PTEST
      IDENT(1)=13
      IDENT(2)=13
      IF(PTEST.GT.ALPHA)RETURN
      IDENT(1)=14
      IDENT(2)=14
      RETURN
      END


      SUBROUTINE PRINT2(TA,TTOT,CODE,BASE,CASE,TBAR,ID,
     *IDENT,ALPHA,RMS,DFD,NN,NR,NTS)
      DIMENSION TA(NTS,NN),TTOT(NTS),CODE(14),BASE(NN),
     *CASE(3),ID(3),IDENT(2),Z(25),XXN1(4),IS(3),XXN2(2),
     *CBAR(25)
      DATA D/0.0/,XXN1/'00','01','10','11'/,XXN2/' 0',' 1'/
900   FORMAT('1'////////1X,T16,'ANOVA FOR SIMPLE SIMPLE MAIN
     *EFFECTS & SIMPLE INTERACTION EFFECTS',/1X,T16,
     *65('-'),/1X,T21,'SOURCE',T38,'SS',T44,'DF',T50,
     *'EFFECT',T62,'F',T67,'P(X.GT.F)',/1X,T18,61('-'))
901   FORMAT(1X,T21,2A1,' AT ',2A1,'(',A2,')',T34,F9.3,
     *T45,'1',2F10.3,T68,F6.4,T76,6A1)
902   FORMAT(/1X,T21,3A1,T34,F9.3,T45,'1',2F10.3,T68,F6.4,
     *T76,6A1)
903   FORMAT(1X,T18,61('-'),/1X,T19,'**  INDICATES THAT',1X,
     *' P(X.GT.F) IS LESS THAN ',F5.4,'  FOR MAIN',/1X,T19,
     *'EFFECTS, IS LESS THAN ',F5.4,' FOR SIMPLE INTERACTION
     *EFFECTS,',/1X,T19,'AND IS LESS THAN ',F5.4,
     *' FOR SIMPLE SIMPLE MAIN EFFECTS.')
904   FORMAT('+')
905   FORMAT(////10X,'ERROR = ',I2,5X,15A1)
906   FORMAT(////1X,T21,'GRAND MEAN = ',F12.4,//1X,T45,
     *14('*'),/1X,T45,'* CELL MEANS *',/1X,T45,14('*'),//1X,
     *T52,A1,/1X,T51,'---',/1X,T36,'(LOW)',T63,'(HIGH)',
     *//1X,T38,A1,T65,A1,/1X,T37,'---',T64,'---',/1X,
     *T30,'(LOW)',T43,'(HIGH)',T57,'(LOW)',T70,
     *'(HIGH)',/1X,T38,':',T65,':',/1X,T21,'(LOW)',
     *F11.4,T38,':',F11.4,T52,F12.4,T65,':',F11.4,
     */1X,T38,':',T65,':',/1X,T19,A1,T26,25('-'),
     *T53,25('-'),/1X,T18,'---',T38,':',T65,':',/1X,T21,
     *'(HIGH)',F10.4,T38,':',F11.4,T52,F12.4,T65,':',
     *F11.4,/1X,T38,':',T65,':')
      DO 10 J=1,25
      Z(J)=0.0
      CBAR(J)=0.0
10    CONTINUE
      BETA=ALPHA/2.0
      THETA=ALPHA/4.0
      CK1=0.0
      CK2=0.0
      CK3=0.0
      DO 50 I=1,NTS
      A1=TA(I,ID(1))
      A2=TA(I,ID(2))
      A3=TA(I,ID(3))
      XA=A1*TTOT(I)
      XB=A2*TTOT(I)
      XC=A3*TTOT(I)
      XAB=A1*A2*TTOT(I)
      XBC=A2*A3*TTOT(I)
      XAC=A1*A3*TTOT(I)
      Z(1)=Z(1)+XA
      Z(2)=Z(2)+XB
      Z(3)=Z(3)+XC
      Z(4)=Z(4)+XAB
```

```
      Z(5)=Z(5)+XAC
      Z(6)=Z(6)+XBC
      Z(7)=Z(7)+A1*A2*A3*TTOT(I)
      IF(A2.LT.D.AND.A3.LT.D) GO TO 11
      GO TO 12
11    IF(A1.LT.0.0) CBAR(1)=CBAR(1)+TTOT(I)
      IF(A1.GT.0.0) CBAR(5)=CBAR(5)+TTOT(I)
12    IF(A2.LT.D.AND.A3.GT.D) GO TO 13
      GO TO 14
13    IF(A1.LT.0.0) CBAR(3)=CBAR(3)+TTOT(I)
      IF(A1.GT.0.0) CBAR(7)=CBAR(7)+TTOT(I)
14    IF(A2.GT.D.AND.A3.LT.D) GO TO 15
      GO TO 16
15    IF(A1.LT.0.0) CBAR(2)=CBAR(2)+TTOT(I)
      IF(A1.GT.0.0) CBAR(6)=CBAR(6)+TTOT(I)
16    IF(A2.GT.D.AND.A3.GT.D) GO TO 17
      GO TO 34
17    IF(A1.LT.0.0) CBAR(4)=CBAR(4)+TTOT(I)
      IF(A1.GT.0.0) CBAR(8)=CBAR(8)+TTOT(I)
34    IF(A3.LT.D) Z(20)=Z(20)+XAB
      IF(A3.GT.D) Z(21)=Z(21)+XAB
      IF(A2.LT.D) Z(22)=Z(22)+XAC
      IF(A2.GT.D) Z(23)=Z(23)+XAC
      IF(A1.LT.D) Z(24)=Z(24)+XBC
      IF(A1.GT.D) Z(25)=Z(25)+XBC
      CK1=CK1+A1
      CK2=CK2+A2
      CK3=CK3+A3
50    CONTINUE
      IF(ABS(CK1)+ABS(CK2)+ABS(CK3).LE..001) GO TO 53
      NERROR=2
      WRITE(6,905) NERROR,(CODE(ID(I)),I=1,3)
      STOP
53    WRITE(6,900)
      Z(8)=CBAR(5)-CBAR(1)
      Z(9)=CBAR(7)-CBAR(3)
      Z(10)=CBAR(6)-CBAR(2)
      Z(11)=CBAR(8)-CBAR(4)
      Z(12)=CBAR(2)-CBAR(1)
      Z(13)=CBAR(4)-CBAR(3)
      Z(14)=CBAR(6)-CBAR(5)
      Z(15)=CBAR(8)-CBAR(7)
      Z(16)=CBAR(3)-CBAR(1)
      Z(17)=CBAR(4)-CBAR(2)
      Z(18)=CBAR(7)-CBAR(5)
      Z(19)=CBAR(8)-CBAR(6)
      X=FLOAT(NR)*FLOAT(NTS)
      Y=X/2.0
      ZX=X/4.0
      ZY=X/8.0
      DO 90 J=1,3
      XX=Z(J)/Y
      Z(J)=Z(J)**2/X
      FS=Z(J)/RMS
      CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
      WRITE(6,902)CODE(ID(J)),CODE(13),CODE(13),Z(J),XX,FS,
     *PTEST,(CODE(IDENT(JS)),JS=1,2)
      DO 80 I=1,4
      KK=7+I+(J-1)*4
      XX=Z(KK)/ZY
      Z(KK)=Z(KK)**2/ZX
      FS=Z(KK)/RMS
      CALL FTEST(IDENT,FS,DFD,PTEST,THETA)
      IF(J.NE.1)GO TO 55
      IS(1)=ID(2)
      IS(2)=ID(3)
      GO TO 70
55    IF(J.NE.2)GO TO 60
      IS(1)=ID(1)
      IS(2)=ID(3)
      GO TO 70
60    IS(1)=ID(1)
```

```
      IS(2)=ID(2)
70    WRITE(6,901)CODE(ID(J)),CODE(13),(CODE(IS(K)),K=1,2),
     *XXN1(I),Z(KK),XX,FS,PTEST,(CODE(IDENT(JX)),JX=1,2)
80    CONTINUE
90    CONTINUE
      DO 200 J=1,3
      IS(3)=13
      XX=Z(3+J)/Y
      Z(3+J)=Z(3+J)**2/X
      FS=Z(3+J)/RMS
      CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
      WRITE(6,904)
      IF(J.NE.1)GO TO 100
      IS(1)=ID(1)
      IS(2)=ID(2)
      GO TO 140
100   IF(J.NE.2)GO TO 110
      IS(1)=ID(1)
      IS(2)=ID(3)
      GO TO 140
110   IS(1)=ID(2)
      IS(2)=ID(3)
140   WRITE(6,902)(CODE(IS(K)),K=1,3),Z(3+J),XX,FS,
     *PTEST,(CODE(IDENT(K)),K=1,2)
      DO 190 K=1,2
      KK=19+K+(J-1)*2
      XX=Z(KK)/ZX
      Z(KK)=Z(KK)**2/Y
      FS=Z(KK)/RMS
      CALL FTEST(IDENT,FS,DFD,PTEST,BETA)
      IF(J.EQ.1)IS(3)=ID(3)
      IF(J.EQ.2)IS(3)=ID(2)
      IF(J.EQ.3)IS(3)=ID(1)
      WRITE(6,901)(CODE(IS(JZ)),JZ=1,3),CODE(13),XXN2(K),
     *Z(KK),XX,FS,PTEST,(CODE(IDENT(JZ)),JZ=1,2)
190   CONTINUE
200   CONTINUE
      XX=Z(7)/Y
      Z(7)=Z(7)**2/X
      FS=Z(7)/RMS
      CALL FTEST(IDENT,FS,DFD,PTEST,ALPHA)
      WRITE(6,902)(CODE(ID(KK)),KK=1,3),Z(7),XX,FS,PTEST,
     *(CODE(IDENT(KK)),KK=1,2)
      WRITE(6,903)ALPHA,BETA,THETA
      DO 233 I=1,8
233   CBAR(I)=CBAR(I)/ZY
      WRITE(6,906)TBAR,CODE(ID(3)),CODE(ID(2)),CODE(ID(2)),
     *(CBAR(I),I=1,4),CODE(ID(1)),(CBAR(I),I=5,8)
      RETURN
      END
```

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